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Elias Loomis

THE

AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

Art. LIII.—Professor Elias Loomis.

A Memorial Address prepared at the request of the President and Fellows of Yale College, by H. A. Newton, and delivered in Osborn Hall, April 11th, 1890.

Elias Loomis was born in the little hamlet of Willington, Conn., August 7th, 1811. His father, the Rev. Hubbell Loomis, was pastor in that country parish from 1804 to 1828. He was a man possessed of considerable scholarship, of positive convictions, and of a willingness to follow at all hazards wherever truth and duty, as he conceived them, might lead. He had studied at Union College, in the class of 1799, though apparently he did not finish the college course with his class. He is enrolled with that class in Union College, and he also received, in 1812, the honorary degree of Master of Arts from Yale College. At a later date he went to Illinois, and there was instrumental in founding the institution which afterwards became Shurtleff College.

Although the boy inherited from his father a mathematical taste, yet his love for the languages also was shown at a very early age. At an age at which many bright boys are still struggling with the reading of English, he is reported to have been reading with ease the New Testament in the original Greek. He prepared for college almost entirely under the instruction of his father. He was, for a single winter only, at the Academy

at Monson, Mass. Owing in part to feeble health he was more disposed, in those early years, to keep to his books than to roam with other boys over the Willington hills. In later life he frequently said that in his early days he never had a thought of asking what subjects he was most fond of, but studied what he was told to study.

At the age of fourteen he was examined and was admitted to Yale College, but owing to feeble health he waited another year before actually entering a class. In college he appears to have been about equally proficient in all of the studies, taking a good rank as a scholar, and maintaining it through his college course. President Porter remembers well the retiring demeanor of the young student, and his concise and often monosyllabic expressions, peculiarities which he retained through life. During his Junior and Senior years he roomed with Alfred E. Perkins whose bequest was the first large endowment of the College Library. He graduated in 1830.

A few weeks before graduation he left New Haven and entered a school, Mount Hope Institute near Baltimore, to teach mathematics, and he remained there for a year and a term. One of his classmates, the late Mr. Cone of Hartford, said that Mr. Loomis had intended to spend his life in teaching, and that it surprised him when he heard that this purpose was abandoned, and that Mr Loomis had gone, in the Autumn of 1831, to the Andover Theological Seminary with the distinct expectation of becoming a preacher. This new purpose was, however, again changed when a year later he was appointed Tutor in Yale College. A vacancy in the Tutorship occurred in the May following (1833), and while not yet twenty-two years of age he returned to New Haven and entered upon the duties of the office. Here he remained for three years and one term. In the spring of 1836 he received the appointment to the chair of Mathematics and Natural Philosophy in Western Reserve College, at Hudson, Ohio. He was allowed to spend the first year in Europe. He was, therefore, during the larger part of the year 1836–7 in Paris attending the lectures of Biot, Poisson, Arago, Dulong, Pouillet and others. He did not visit Germany because of want of money. A long series of letters written by him at this time appeared in the Ohio Observer, and

the contrast between England and France as he saw them, and the same places as seen by the tourist to-day is decidedly interesting.

He purchased in London and Paris apparatus for his professorship, and the outfit for a small observatory, and in the Autumn of 1837 began his labors at Hudson. Here he remained for seven years, maintaining with unflagging perseverance both his work in teaching and his scientific labors. In judging of this work at Hudson we must remember that he was not with perfect surroundings. He was without an assistant and without the counsel and encouragement of associates in his own branches of science. The financial troubles which culminated in this country in 1837 were peculiarly severe upon the young and struggling College. Money was almost unknown in business circles in Ohio, trade being almost entirely in barter. In this way principally was paid so much of the promised salary of $600 per annum as was not in arrears. In one of his letters he congratulates himself that all of his bills that were more than two years old had been paid. In another he says that there was not enough money in the college treasury to take him out of the state. When he left Hudson the College offered to pay at once the arrears of his salary by deeding to him some of its unimproved lands.

In 1844 he was offered, and he accepted, the office of Professor of Mathematics and Natural Philosophy in the University of New York. In this new position he undertook the preparation of a series of text books in the Mathematics, and for some years a large part of the time which he could spare from his regular college work was given to the preparation of these books.

When Professor Henry resigned his professorship at Princeton in order to accept the office of Secretary of the Smithsonian Institution, Professor Loomis was offered the vacant chair. He went to Princeton and remained there during one year, at the end of which he was induced to return again to his old place in the University of New York. Here he continued until 1860, when he was elected to the Professorship in Yale College made vacant by the death of Professor Olmsted. For the last twenty-nine years of his life, he here labored for the

College and for science, passing away on the 15th of August, 1889.

Let us look now in succession at the different lines of his activity during these fifty-six years,—four here in the tutorship and in Europe; seven at Hudson, Ohio; sixteen in New York City and Princeton; and twenty-nine in New Haven.

For the first year on returning from Andover to New Haven, he was tutor in Latin, although it seems that he might, had he chosen it, have been tutor of Mathematics. I believe that at the beginning his mind was not yet definitely turned toward the exact sciences. In his childhood he had taken specially to Greek. In college he was equally proficient in all of his studies. He is represented to have led his class at Andover in Hebrew, and now on entering the tutorship he chose to teach the Latin language and literature. During the second year he taught Mathematics, and the third year Natural Philosophy. His later success in scientific work was, I believe, in no small measure due to his earlier broad and thorough study of language.

I have made some inquiry in order to learn what it was that turned his attention and tastes toward science. One of his colleagues in the tutorship, the Rev. Dr. Davenport, says that he recollects very distinctly the first indication to his own mind that Tutor Loomis was turning his thoughts in this direction. The great meteoric shower of 1833 came early in the period of his tutorship, and the views of Professor Twining and Professor Olmsted about the astronomical character and origin of these interesting and mysterious bodies were a common topic of conversation among scientific men in the College, especially whenever Professor Olmsted was present. The tutors were accustomed to meet as a club from time to time in the tutors' rooms in turn, and Dr. Davenport well recollects the occasion when Tutor Loomis brought in a globe and discussed before the club the new theories about these bodies. Up to this time Tutor Loomis had seemed to him to have given his thoughts and study to language rather than to science.

In January, 1834, there were constituted in the Connecticut Academy of Arts and Sciences twelve committees representing the several departments of knowledge, and Tutor Loomis was

put on the Committee on Mathematics and Natural Philosophy. These are the only signs of scientific taste or activity which I have detected earlier than the autumn of 1834, after he had been a year and a term in the tutorship. From this time on to the end of his life, he gave his time and energies to several subjects that are enough distinct one from the other to make it convenient to disregard a strictly chronological account of his labors, and consider his work in each subject by itself.

A subject of which he early undertook the investigation was *Terrestrial Magnetism.* We often use the rhetorical phrase "True as the needle to the pole," but, looked at carefully, the magnetic needle is anything but constant in direction; like the weather vane on the steeple, it is ever in motion, swinging back and forth, in motions minute and slow it is true, but still always swinging. It has fitfully irregular motions;—it has motions with a daily period;—motions with an annual period; and motions whose oscillations require centuries for completion.

The *daily* motions of the magnetic needle were those which Tutor Loomis first studied. At the beginning of the second year of his tutorship he set up by the north window of his room in North College a heavy wooden block, and on it the variation compass that belongs to the College. Here for over thirteen months, he observed the position of the needle at hourly intervals in the day time, his observations usually being for seventeen successive hours of each day.

The results of these observations, together with a special discussion of the extraordinary cases of disturbance, were published in the American Journal of Science in 1836. No similar observations of the kind made in this country had at that time been published. So far as I am aware, none made before 1834 have since been published, except ten days observations made by Professor Bache in 1832. In fact, I know of only one or two like series of hourly observations made in Europe earlier than these by Tutor Loomis. He also at this time formed the purpose of collecting all the observations of magnetic declination that had been hitherto made in the United States, and of constructing from them a magnetic chart of the country. He appealed successfully to the Connecticut

Academy of Arts and Sciences for its sympathy and aid. The work of collecting facts was so far advanced before leaving New Haven that when he had been a few months Professor at Hudson, he forwarded to the American Journal of Science a discussion of the observations thus far obtained, and with them a map of the United States, with the lines of equal deviation of the needle drawn upon it. Two years later he published additional observations and a revised edition of this map.

These were the first published magnetic charts of the United States, and though the materials for their construction were not numerous, and in many cases those obtainable were not entirely trustworthy, yet sixteen years later, when a map was made by the United States Coast Survey from later and more numerous data, Professor Bache declared that between his own new map and that of Professor Loomis, when proper allowance had been made for the secular changes, the "*agreement was remarkable.*"

The northern end of a perfectly balanced magnetic needle turns downward, and the angle it makes with the horizon is called the magnetic *dip*. This angle is an important one, and is observed with accuracy only by using an expensive instrument, and taking unusual pains in observing. Hence only a few observations of this element were found by Professor Loomis. From these, however, he ventured to put on his first magnetic map a few lines that exhibited the amount of the *dip*.

While he was in Europe he purchased a first class dipping needle, for Western Reserve College, and at Hudson and the neighborhood in term time, and at other places in vacation, he made observations with this needle. Some of these observations were made before his second magnetic chart was published, and upon this map were now given tolerably good positions of the lines of equal magnetic dip. But he continued his observations for several years, determining the dip at over seventy stations, spread over thirteen states, each determination being the mean of from 160 to over 4,000 readings. These observations were published in several successive papers in the transactions of the American Philosophical Society at Philadelphia.

Various papers on terrestrial magnetism, in continuation of his earlier investigations, appeared in 1842, in 1844, in 1847, and in 1859, but movements in Germany, England and Russia had meanwhile been inaugurated which led to the establishment by governments of a score of well equipped magnetic observatories, and this subject passed largely out of private hands.

Closely connected with terrestrial magnetism, and to be considered with it, is the *Aurora Borealis*. In the week that covered the end of August and the beginning of September, 1859, there occurred an exceedingly brilliant display of the Northern Lights. Believing that an exhaustive discussion of a single aurora promised to do more for the promotion of science than an imperfect study of an indefinite number of them, Professor Loomis undertook at once to collect and to collate accounts of this display. A large number of such accounts were secured from North America, from Europe, from Asia, and from places in the Southern Hemisphere; especially all the reports from the Smithsonian observers and correspondents, were placed in his hands by the Secretary, Professor Henry.

These observations and the discussions of them were given to the public during the following two years, in a series of nine papers in the American Journal of Science.

Few, if any, displays on record were as remarkable as was this one for brilliancy and for geographical extent. Certainly about no aurora have there been collected so many facts. The display continued for a week. The luminous region entirely encircled the North Pole of the earth. It extended on this continent on the 2d of September as far south as Cuba, and to an unknown distance to the north. In altitude the bases of the columns of light were about fifty miles above the earth's surface, and the streamers shot up at times to a height of five hundred miles. Thus over a broad belt on both continents this large region above the lower atmosphere was filled with masses of luminous material. A display similar to this, and possibly of equal brilliancy, was at the same time witnessed in the Southern Hemisphere.

The nine papers were mainly devoted to the statements of observers. Professor Loomis, however, went on to collect

facts about other auroras, and to make inductions from the whole of the material thus brought together. He showed that there was good reason for believing that not only was this display represented by a corresponding one in the Southern Hemisphere, but that all remarkable displays in either hemisphere are accompanied by corresponding ones in the other.

He showed also that all the principal phenomena of electricity were developed during the auroral display of 1859; that light was developed in passing from one conductor to another, that heat in poor conductors, that the peculiar electric shock to the animal system, the excitement of magnetism in irons, the deflection of the magnetic needle, the decomposition of chemical solutions, each and all were produced during the Auroral storm, and evidently by its agency. There were also in America effects upon the telegraph that were entirely consistent with the assumption previously made by Walker for England, that currents of electricity moved from northeast to southwest across the country. From the observations of the motion of auroral beams, he showed that they also moved from north-northeast to south-southwest, there being thus a general correspondence in motion between the electrical currents and the motion of the beams.

When there is a special magnetic disturbance at any place, there is usually a similar one at all other neighboring places. But these disturbances do not occur at the several places at the same instant of time. Professor Loomis showed that in the United States they take place in succession as we go from northeast to southwest, the velocity of the wave of disturbance being over one hundred miles per minute. The waves of magnetic irregularities were thus connected with the electrical current and with the drifting motions of the streamers in the auroral display.

As incident to this discussion, he collected all available observations of auroras, and he deduced from them the annual number of auroras visible at each place of observation. These numbers, when written upon a chart of the Northern Hemisphere, showed that auroras were by no means equally distributed over the earth's surface. It was found that the region in which they occurred most frequently was a belt or

zone of moderate breadth and of oval form, enclosing the North Pole of the earth, and also the North Magnetic Pole. It was therefore much farther south in the Western hemisphere than in the Eastern. Along the central line of this belt there are more than eighty auroras annually, but on going either north or south from the central line of that belt the number diminishes.

In 1870 Professor Loomis published a paper of importance relating to terrestrial magnetism, in which he showed its connection and that of the aurora with spots on the sun. That the spots on the sun had periods of maximum and minimum development had long been known. Lamont had noticed a periodicity in the magnetic diurnal variations. Sabine and Wolf and Gauthier had noticed that the two periodicities were allied. The connection of the period of solar spots with conjunction and opposition of certain planets had been shown by De La Rue and Stewart. Professor Loomis undertook an exhaustive examination of the facts that tended to confirm or refute the propositions that had been advanced. He confirmed and added to the conclusions of Messrs. De La Rue and Stewart. He also brought together such facts as were relevant to the question, and he showed that the regular diurnal variation of the magnetic needle was entirely independent of the solar spots, but that those disturbances that were excessive in amount were almost exactly proportional to the spotted surface of the sun. He also showed that great disturbances of the earth's magnetism are accompanied by unusual disturbances on the sun's surface on the very day of the storm.

Various forms of periodicity in the aurora have frequently been suggested. Professor Loomis, from all available accounts of the aurora, was able to show that while in the center of the zone of greatest auroral frequency auroras might be visible nearly every night, and hence that periodicity could not easily be shown by means of numbers of auroras recorded in such places, yet that such periodicity was distinctly traceable at places where the average number seen was about twenty or twenty-five a year. The times of maxima and minima of the solar spots were seen to correspond in a remarkable manner with the maxima and minima in the frequency of auroral displays

in these middle latitudes. Also from the daily observations made by Messrs. Herrick and Bradley at New Haven during seventeen years, he concluded that auroral displays in the middle latitudes of America are generally accompanied by an unusual disturbance of the sun's surface on the very day of the aurora. The magnetism of the earth, the Aurora Borealis, and the spots on the sun, have thus all three a causal connection, and apparently that connection is closely related to the conjunctions and oppositions of certain planets.

Shortly after the publication of this memoir, Professor Lovering published his extensive catalogue of auroras. A further discussion of the periodicity of the auroras was undertaken by Professor Loomis and published in 1873. In this he made use of all the auroras recorded in Professor Lovering's catalogue. They confirmed his previous conclusions, only slight modifications being required by the new facts presented, and by their more systematic collation.

In these papers, as in most of his papers upon other subjects, Professor Loomis was ever intent upon answering the questions: What are the laws of nature? What do the phenomena teach us? To establish laws which had been already formulated by others, but which still needed confirmation, was to him equally important with the formulation and proof of laws entirely new.

Let us now turn to another important line of Professor Loomis's work,—*Astronomy*. As I have said, he was early interested in the shooting stars. In October, 1834, he read a paper before the Connecticut Academy of Arts and Sciences upon this subject, probably in substance that which was shortly afterward published in this Journal. The published paper is principally a restatement of the observations made in Germany in 1823 by Brandes in concert with his pupils for determining the paths of the stars through the atmosphere, together with methods of computation. From the results of Brandes' observations, however, he deduces an argument for the cosmic character of the shooting stars. One month after reading this paper to the Connecticut Academy he engaged in similar concerted observations with Professor Twining, who was then

residing near West Point, N. Y. These were only moderately successful, but they were the first observations of the kind undertaken in America.

During the senior year of his college course there arrived at New Haven the five-inch telescope, given to the college by Mr. Sheldon Clark, constructed by Dolland. This instrument was much larger than any telescope then in the country. It was temporarily placed in the Athenæum tower, where it was mounted on castors and wheeled to the windows for use. This temporary abode it occupied, however, for over thirty years. In spite of its miserable location it was, in the decade following its instalment, a power in the development of the study of astronomy in the college. The lives and works of Barnard, and Loomis, and Mason, and Herrick, and Lyman, and Chauvenet, and Hubbard, and of other graduates of the college prove this. What rich returns for Mr. Sheldon Clark's twelve-hundred-dollar investment!

In 1835 the return of Halley's comet had been predicted, and its appearance was eagerly expected by astronomers and the public: Professor Olmsted and Tutor Loomis first in this country caught sight of the stranger, and throughout its course they noted its physical appearances. With such means as he had at command, Mr. Loomis observed the body's place, and computed from his observations the orbit.

The latitude and longitude of an observatory are constants to be early determined. These were measured by President Day for Yale College in 1811. In the summer of 1835 Tutor Loomis, with such instruments as the college possessed, a sextant and a small portable transit, made numerous observations of Polaris for latitude, and several moon culminations for longitude. From these he computed the latitude and longitude of the Athenæum tower. The longitude from Greenwich though obtained from a small number of observations, differs less than two seconds of time from our best determinations to-day.

While in Europe in 1836–37 Professor Loomis, as I have said, bought for Western Reserve College the instruments for an observatory. These were a four-inch equatorial, a transit instrument and an astronomical clock. On his return he

erected, in 1837, a small observatory at Hudson, and in September, 1838, began to use the instruments. He had no assistant, and by day had a full allotment of college work. Two hundred and sixty moon culminations and sixteen occultations observed for longitude, sixty-nine culminations of Polaris for latitude, along with observations on five comets, sufficiently extended for a computation of their orbits; these attested his activity outside of his required duties. Some years later, when the corresponding European observations were made public, he prepared an elaborate discussion of these longitude observations, and published it in *Gould's Astronomical Journal.* A sixth comet was observed by him at Hudson in 1850.

It may not seem a very large output of work in six years' time to have determined the location of the Observatory, and to have observed five comets. But we must recollect that the telegraph had not then been invented, that the exact determination of the longitude of a single point in the western country had a higher value then than it can have now, and that it could be obtained only by slow and tedious methods. These were, moreover, days of small things in astronomy in this country. At Yale College we had a telescope but not an observatory. At Williamstown an observatory had been constructed, but it was used for instruction, not for original work. At Washington Lieutenant Gilliss, and at Dorchester Mr. Bond, were commissioned by the government in 1838 to observe moon culminations in correspondence with the observers in the Wilkes exploring expedition for determining their longitude. These two prospective sets of observations, both of them under government auspices and pay, were the only signs of systematic astronomical activity in the United States outside of Hudson, when in 1838 Professor Loomis began his observing there. In his Inaugural Address he asks: "Where now is our American Observatory? Where throughout this rich and powerful nation do you find a single spot where astronomical observations are regularly and systematically made? There is no such spot." When he left Hudson in 1844 the situation was not largely changed. Mr. Bond had removed his instruments and work to Cambridge. The High School Observatory at Philadelphia had been erected and Messrs. Walker and

Kendall were using its instruments. Professor Bartlett had built the observatory at West Point, and had begun to observe there. Lieutenant Gilliss after years of excellent work in the little establishment on Capitol Hill had just finished the present Naval Observatory building at Washington, Professor Mitchel had begun to build the Cincinnati Observatory, and the Georgetown Observatory building had been erected. Professor Loomis's work at Hudson should be measured by what others were doing at the time, rather than by the larger performance of to-day.

In the summer of 1844, the year in which Professor Loomis came to New York, a new method in Astronomy had its first beginnings. The telegraph line had just been built between Baltimore and Washington, and Captain Wilkes at Baltimore compared his chronometer by telegraph with one at Washington, and so determined the difference of longitude of the two places.

Professor Bache was now Superintendent of the Coast Survey, and he determined at once to use the new method for the purposes of the survey. To Mr. Sears C. Walker was committed the direction of the work, but scarcely less important were the services of Professor Loomis, who for three campaigns had charge of the end of the lines in Jersey City and New York. Their first partially successful efforts were made in 1846, but the practical difficulties were overcome and entire success was obtained by them in 1847 and 1848. In these years the differences of longitude of Washington, Philadelphia, New York and Cambridge were thus determined with an accuracy far greater than any previous similar determination whatsoever.

The next summer, that of 1849, Professor Loomis assisted in a like work to connect Hudson, Ohio, with the eastern stations. His observations of moon culminations at Hudson were thus available equally with those made at Philadelphia, Washington, Dorchester and Cambridge for determining the absolute longitudes of Atlantic stations from Greenwich. It was not until 1852 that European astronomers began to use these telegraphic methods in measuring longitudes.

In 1850 Professor Loomis published a volume on the *Recent*

Progress of Astronomy, especially in the United States. A first and a second edition were soon exhausted, and in 1856 the volume was entirely rewritten and very much enlarged. Some of the topics in these volumes were the subjects of articles communicated from time to time to the public in this Journal, *Harper's Magazine*, and other periodicals. Another important contribution to astronomy appeared in 1865, that is, his *Introduction to Practical Astronomy.* Eminent astronomers in England and America have expressed in the highest terms their praise of this book. Though it is now thirty-five years since its first appearance, and many treatises on the same subject, some elaborate and some elementary, have since been published, yet for an introduction to practical work I believe that a student will find this volume better than any other for his uses at the beginning of his course.

The increase of our knowledge in astronomy was, from first to last, an object of special interest to Professor Loomis. Before he left New York the income from his text-books enabled him to make to Yale College the generous offer of coming to New Haven and working in an observatory at his own charges, provided a suitable observatory should be constructed and equipped for him. Unfortunately, the college was not able, although it was greatly desirous of doing it, to avail itself of his generous offer. Near the same time he joined with public spirited citizens of New York in an effort to establish an astronomical observatory in or near that city, and for that purpose an act of incorporation was obtained from the New York State Legislature. After coming to New Haven, he always took the warmest interest in the plans of Mr. Winchester for the establishment of an observatory in connection with Yale University. His counsel and assistance have been instrumental, more than the public could know, in producing and preserving whatever of value has been developed in that observatory.

The science of *Meteorology* has, however, been that in which Professor Loomis has made the most important contributions to human knowledge.

Shortly after his graduation in 1830 and before he entered

upon the tutorship, there appeared the first of a long series of papers by Mr. Redfield, of New York City, upon the theory of storms. In the last year of his tutorship there appeared also the first of a like remarkable series of papers on the same subject by Professor Espy of Philadelphia. Two rival theories were advocated by these two men, and these theories became the subject of no little discussion in scientific meetings, and in scientific journals, for a long period of years. Professor Loomis had, from their very inception, taken a warm interest in these discussions, and the subject of meteorology, and in particular its central problem the theory of storms, held in his thought and work the first place from that time to the day of his death.

In his visit to Europe the year before he went to Hudson, he purchased a set of meteorological instruments, and for several years in Hudson he steadily performed the naturally irksome task of making twice each day a complete set of meteorological observations. A few weeks after he entered upon his professorship in Hudson a tornado passed five miles from that place, and he went out immediately to examine the track and learn what facts he could that should bear upon the theory of the tornado. The results were valuable, but he was not altogether satisfied with them. They led him, however, to undertake the discussion of one of the large storms that covered the whole United States.

For this purpose he selected the storm which had occurred near the 20th of December, 1836. Sir John Herschel had recommended that hourly observations be taken by all meteorological observers on four term days in the year, that is, observations for thirty-six successive hours at each equinox and each solstice. This storm fell partly upon one of these term days. Professor Loomis set to work to collect all the meteorological observations made during the week of the storm that he could obtain from all parts of the United States, and from some stations in Canada. The discussion resulting therefrom was read in March, 1840, before the American Philosophical Society at Philadelphia.

Let us for a little while consider the amount of knowledge of the facts about storms in our possession in 1840, the date

when this memoir was read and an abstract of it published in Philadelphia. Franklin had noted the motion of storms from southwest to northeast. He said:* "Our northeast storms in North America begin first in point of time in the southwest parts, that is to say, the air in Georgia, the farthest of our colonies to the southwest, begins to move southwesterly before the air of Carolina, which is the next colony northeastward; the air of Carolina has the same motion before the air of Virginia, which lies still more northeastward; and so on northeasterly through Pennsylvania, New York, New England, etc., quite to Newfoundland." Redfield had traced several storms along the West India Islands northwesterly until about in the latitude of 30° their course was turned quite abruptly and they swept off northeasterly along the Atlantic coast toward and even past Newfoundland. Espy found some storms moving easterly or south of east from the Mississippi to the Atlantic.

Brandes had announced as a law that the wind in storms blows inward toward a center; but his law was an induction from a small number of observations. Dove had contended for a whirling motion; Redfield advanced facts to show that the winds blew in circles anti-clockwise around a center that advanced in the direction of the prevalent winds, and with him agreed Reid, Piddington and others. Espy, agreeing with Brandes, claimed that the observations in the various storms showed a centripetal motion of the winds, toward a center if the region covered by the storm was round, and toward a central line if the storm region was longer in one direction than in another. Espy's conclusions were intimately connected with his theory that in the center of the storm there was an upward motion of the air, and that the condensation of vapor into rain furnished the energy needed for the continuation of the storm. The rival theories of Redfield and Espy were in sharp contest on several points, but the main contention was around this central question: Do the winds blow in circular whirls, or do they blow in toward a center? New York State was collecting observations from the Academies. The American Philosophical Society and the Franklin Insti-

* Letter to Alexander Small, May 12, 1760.

tute, aided by an appropriation from the State of Pennsylvania, had united in an effort to learn the facts and the true theory of storms.

Under such circumstances the thorough discussion of a single violent storm was likely to add materially to our knowledge. The treatment of this storm by Professor Loomis was probably more complete than that of any previous one, and the methods which he employed were better fitted to elicit the truth than any earlier methods. But the storm was a very large one, extending from the Gulf of Mexico to an unknown distance north, and having its center apparently to the north of all the observers. The results which he was able to secure did not sustain either of the two rival theories, but rather tended to prove some features in each of them. Professor Loomis was not himself satisfied with them, and he therefore waited for another storm that should be better fitted for examination.

In the month of February, 1842, a second tornado passed over northeastern Ohio, and Professor Loomis with one of his colleagues again started out for the examination of the track. The tornado passed over a piece of woods, and hence the positions of the prostrate trees showed clearly the motion of the wind in the passing tornado, and threw much light upon the character of this kind of storm. But the tornado was a single feature of a large storm that covered the whole country, and a second storm of great intensity was also experienced in the same month.

The discussion of these two storms was now undertaken by him. The paper giving the results of that discussion was sent to Professor Bache, and read by him at the centennial meeting of the American Philosophical Society, in May, 1843, and created, as Professor Bache wrote, a great sensation. It was at the time important for the light which it threw upon the rival contending theories of Espy and of Redfield, but it was more important by far by reason of the new method of investigation then for the first time employed.

In the paper upon the storm of 1836 Professor Loomis had made some advance upon previous methods of representing the

facts about storms. But even the method he then used was entirely unfitted to give answers to the questions which meteorologists were asking. Some of those questions were stated in circulars issued by the joint committee of the American Philosophical Society and the Franklin Institute: What are the phases of the great storms of rain and snow that traverse our continent; what their shape and size; in what direction, and with what velocity do their centers move along the surface of the earth; are they round, or oblong, or irregular in shape; do they move in different directions in different seasons of the year?

The graphic representation by Professor Loomis on the map of the United States of the storm of 1836 had been a series of lines drawn joining the places where at a given hour the barometer was at its lowest point. That line would so far as the barometer was concerned mark for that hour the central line of the storm. The progress of the line from hour to hour on the map showed, quite imperfectly, how the storm had traveled. Some arrows added showed to the eye also certain facts about the movements of the air.

Professor Espy adopted and thereafter adhered to a modification of this method of representing storm phenomena, and I think meteorologists will agree with me in my opinion that Professor Espy's four Reports from 1842 to 1854 though they contained an immense accumulation of facts, were because of this radical defect of presentation almost useless to meteorological science.

In the discussion of the storms of 1842, instead of the line of minimum depression of the barometer, Professor Loomis drew on the map a series of lines of equal barometric pressure, or rather of equal deviations from the normal average pressure for each place. A series of maps representing the storm at successive intervals of twelve hours were thus constructed, upon each of which was drawn a line through all places where the barometer stood at its normal or average height. A second line was drawn through all places where the barometer stood $\frac{2}{10}$ of an inch below the normal; and other lines through points where the barometer was $\frac{4}{10}$ below, $\frac{6}{10}$ below, $\frac{8}{10}$ below, etc.; also lines were drawn through those points

where the barometer stood $\frac{2}{10}$, $\frac{4}{10}$, $\frac{6}{10}$, etc. above its normal height. The deviations of the barometric pressure from the normal were thus made prominent, and all other phenomena of the storm were regarded as related to those barometric lines. A series of colors represented respectively the places where the sky was clear, where the sky was overcast, and where rain or snow was falling. A series of lines represented the places at which the temperature was at the normal, or was 10 or 20 or 30 degrees above the normal, or below the normal. Arrows of proper direction and length represented the direction and the intensity of the winds at the different stations. These successive maps for the three or four days of the storm furnished to the eye all its phenomena in a simple and most effective manner.

You have no doubt, most of you, already recognized in this description the charts, which to-day are so common, issued by the United States Signal Service, and by weather service Bureaus in other countries. The method seems so natural that it should occur to any person who has the subject of a storm under consideration. But the greatest inventions are ofttimes the simplest, and I am inclined to believe that the introduction of this single method of representing and discussing the phenomena of a storm was the greatest of the services which our colleague rendered to science. This method is at the foundation of what is sometimes called "the new meteorology," and the paper which contains its first presentation stands forth, I am convinced, as the most important paper in the history of that science. I regret that I cannot aid my memory by quoting the exact words, but I remember distinctly what seemed to me an almost despairing expression made many years ago by one who had high responsibility in the matter of meteorological work, as he looked out upon the confused mass of observations already made, and felt unable to say in what direction progress was to be expected. With this I contrast the buoyant expressions of another officer charged with like responsibility, as he showed me, one or two decades later (in 1869), charts constructed like those of Professor Loomis, and said, "I care not for the mass of observations made in the usual form. What I want is the power and the material for

making such charts as these." These two expressions of Sir George Airy and of LeVerrier mark the progress and the direction of progress in meteorology developed by Professor Loomis's memoir.

What was his own judgment of the method at the time of its publication and its value in meteorology, can be seen from his words at the close of the memoir, which I beg permission to quote.

"It appears to me that if the course of investigations adopted with respect to the two storms of February, 1842, was systematically pursued we should soon have some settled principles in meteorology. If we could be furnished with two meteorological charts of the United States daily for one year, charts showing the state of the barometer, thermometer, winds, sky, etc., for every part of the country, it would settle forever the laws of storms. No false theory could stand against such an array of testimony. Such a set of maps would be worth more than all which has been hitherto done in meteorology. Moreover, the subject would be well nigh exhausted. But one year's observation would be needed. The storms of one year are probably but a repetition of those of the preceding. Instead then of the guerilla warfare which has been maintained for centuries with indifferent success, although at the expense of great self-devotion on the part of individual chiefs, is it not time to embark in a general meteorological crusade? A well arranged system of observations spread over the country, would accomplish more in one year, than observations at a few insulated posts, however accurate and complete, continued to the end of time. The United States are favorably situated for such an enterprise. Observations spread over a smaller territory would be inadequate, as they would not show the extent of any large storm. If we take a survey of the entire globe, we shall search in vain for more than one equal area which could be occupied by the same number of trusty observers. In Europe there is opportunity for a like organization, but with this incumbrance, that it must needs embrace several nations of different languages and governments. The United States then afford decidedly the most hopeful field for such an enterprise. Shall we hesitate to embark in it; or shall we grope timidly along as

in former years? There are but few questions of science which can be prosecuted in this country to the same advantage as in Europe. Here is one where the advantage is in our favor. Would it not be wise to devote our main strength to the reduction of this fortress? We need observers spread over the entire country at distances from each other not more than fifty miles. This would require five or six hundred observers for the United States. About half this number of registers are now kept in one shape or another, and the number by suitable efforts might probably be doubled. Supervision is needed to introduce uniformity throughout, and to render some of the registers more complete. Is not such an enterprise worthy of the American Philosophical Society? The general government has for more than twenty years done something, and has lately manifested a disposition to do more for this object. If private zeal could be more generally enlisted, the war might soon be ended, and men would cease to ridicule the idea of our being able to predict an approaching storm."

This plan of a systematic meteorological campaign was cordially seconded by Professors Bache and Peirce. At a somewhat later date the American Academy of Sciences of Boston appointed a committee, of which Professor Loomis was chairman, to urge upon the proper authorities the execution of the plan. The American Philosophical Society of Philadelphia united its voice with that of the Academy. About this time Professor Henry was made Secretary of the Smithsonian Institution. He determined to make American meteorology one of the leading subjects of investigation to be aided by the Institution. At Professor Henry's request Professor Loomis prepared a report upon the meteorology of the United States, in which he showed what advantages society might expect from the study of the phenomena of storms; what had been done in this country toward making the necessary observations, and toward deducing from them general laws; and finally, what encouragement there was to a further prosecution of the same researches. He then presented in detail a practicable plan for securing the hoped-for advantages in their fullest extent.

This plan looked to a unifying of all the work done by existing observers, a systematic supervision, a supplementing

of it by new observers at needed points, a securing of the coöperation of the British government and the Hudson's Bay Company in the regions to the north of us, and finally a thorough discussion of the observations collected. A siege of three years was contemplated. In the history of the several steps that finally led to the establishment of the United States Signal Service, this report has an important place.

The scheme laid down by Professor Loomis was in part followed out by the Institution. But the fragmentary character of the observations, the want of systematic distribution of the places of the observers, and the imperfections of the barometers, made the material collected difficult of discussion. Professor Loomis waited in hopes of some better system.

In 1854, Professor Loomis undertook a rediscussion of the storm of 1836, using the new methods introduced for treating the storms of 1842. A visit to Europe shortly after enabled him to collect a large number of observations upon a storm or series of storms that occurred in Europe about a week later than that American storm. He had long been anxious to connect, if possible, these two storms, as he said, "stepping across the Atlantic." The European and the American storms, however, not only proved to be distinct one from the other, but the discussion showed clearly that many of the laws of American storms were radically different from those of the European storms. The results of the whole discussion were published in 1859 by the Smithsonian Institution.

Upon coming to New Haven, in 1860, he commenced the collection of all the meteorological observations that had been made in New Haven and the immediate vicinity, and succeeded in finding sets which, when brought together, made up a nearly continuous record through 86 years. The results of these observations formed the subject of a memoir published by the Connecticut Academy of Arts and Sciences in 1866.

It became part of his duties in college to deliver a course of lectures upon the subject of meteorology. In preparation for these he caused to be printed in very limited numbers the outlines of a treatise upon meteorology, to be used as the basis of his series of lectures. In 1868 he developed this outline into a treatise suited to use in college classes and in private study.

This treatise, notwithstanding the rapid advances of the science during more than twenty years, is still indispensable to the student of meteorology.

The better system of observing, for which Professor Loomis had been long waiting, came when the United States Signal Service was established in 1871. The daily maps of the weather published by the Bureau were constructed essentially after the plan which Professor Loomis had, thirty years before, invented for the treatment of the storms of 1842. As soon as these maps had been been published for the two years 1872 and 1873, Professor Loomis commenced in earnest to deduce from them the lessons which they taught us respecting the nature and the phenomena of United States storms. To this investigation he gave nearly all his energies during the remaining fifteen years of his life.

For several years he employed and paid for the services of assistants whose time was given to the preparation of material for use in his studies. The aggregate cost of this assistance was of itself a very large contribution to science. Beginning in April, 1874, he presented regularly at eighteen successive meetings of the National Academy of Sciences in April and in October of each year, a paper entitled "Contributions to Meteorology." These were at first based upon the publications of the Signal Service alone, but as years went by like publications appeared in Europe that were useful for his work. These papers were published in July and January following the Academy meeting, and they regularly formed the first and leading article in eighteen successive volumes of the American Journal of Science. Gradually, one after another of his college duties were committed to others that he might give his whole strength to these investigations.

An attack of malaria interrupted the regularity of the series. His advancing years and diminishing strength warned him that the end of his investigations could not be far distant. The number of hours in which he could work each day was slowly diminishing. Five more papers followed at somewhat less regular intervals.

In 1884 he began a revision of the whole series of papers. They had been presented without much regard to systematic

order in the subjects investigated, and new material had accumulated from time to time, so that a thorough, systematic revision seemed absolutely necessary.

In 1885 he presented to the Academy of Sciences the first chapter of this revision, in which he discussed the areas of low pressure—their form, their size, their motions, and the phenomena attending them. Two years later, in 1887, the second chapter of the revision appeared, in which he discussed the areas of high pressure, their form, magnitude, direction and velocity of movement, and their relation to areas of low pressure. Gradually his physical strength was failing, though his mind was as bright and clear as ever. To this work, the only work which he was now doing, he was able to give two or three hours a day. Anxiously he husbanded his strength, slowly and painfully preparing the diagrams and the tables for the third chapter upon rain areas, the phenomena of rainfall in its connection with areas of low pressure, and the varied phenomena of unusual rainfall. "I see," he said to a friend, "not the end of this subject, but where I must stop. I hope I shall have strength to finish this work, and then I shall be ready to die."

This third and finishing chapter was finally passed through the printer's hands and some advance copies distributed to correspondents abroad in the summer months of 1889. His work upon the theory of storms he felt was finished. As he paid the bill of the printer, he said to him: "When I return at the close of the vacation I expect to put into your hands for printing a new edition of the *Loomis Genealogy*." Before the close of the vacation he died.

These three chapters of his revised edition of *Contributions to Meteorology* constitute the full and ripe fruitage of his work in his favorite science. They will for a long time to come be the basis of facts by which writers in theoretical meteorology must test their formulas. They cover all the important points taken up in the twenty-three earlier memoirs,—with one important exception, the relation of mountain observations to those made on the plains below. The laws connecting these two are not yet clearly indicated; much remains to be learned about them, and they are of the utmost importance in theoret-

ical meteorology. He felt most deeply the backward steps taken by the United States Signal Service when mountain observations and the publication of the *International Bulletin* were discontinued. "The National Academy of Sciences," he said, "ought at once to take up the subject and use all its influence to secure the restoration of these two services."

Professor Loomis at various times studied certain other questions in physics and astronomy that were more or less allied with the subjects to which he gave the principal part of his time, and he published the results of his studies. He made a series of experiments on currents of electricity generated by a plate of zinc buried in the earth. He examined the electrical phenomena in certain houses in New York; the curious phenomena of optical moving figures; the vibrations sent out from waterfalls as the water flows over certain dams; the orbits of the satellites of Uranus; the temperature of the planets; the variations of light of the stars η Argus and Algol; and the comet of 1861.

The subject of family *Genealogy* has a peculiar fascination to many minds. It would be an interesting study to determine practically by a collection of facts what are the elements in a man's character which lead him to engage in this peculiar study. Certain it is that men of most diverse disposition are led into it. I should not have thought it likely that Professor Loomis would have taken up the subject very seriously. Others have expressed to me the same thought, and he himself says that he did not think it strange that others should be surprised at his devoting so much time to this subject, for he was surprised at it himself. He became interested in the subject early in life, and that interest remained unbroken to his last days. For near forty years before his first publication he collected from time to time materials for a list of the descendants of his ancestor, Joseph Loomis, who came from Braintree, England, in the year 1638, and settled in Windsor, Connecticut, in 1639. In each of his four visits to Europe he extended his inquiries to his ancestor's earlier history in England. The materials thus collected were put in type in 1870. He published a list containing 4,340 descendants of

Joseph Loomis bearing the Loomis name. He regarded it as entirely provisional, printed to help himself in making further researches, and to excite interest in others of the name, who would thus be led to give additional information, or correction of errors.

Finding that to a limited extent only could he hope by correspondence to gain the information desired, he now undertook in his vacations to canvass the country by personal visits. He collected lists of names from every available source, from catalogues of every description, from city directories, county directories, county maps and county tax lists, and he compiled from these sources lists of all the Loomis names he could find. Arranging these names by counties he undertook to visit each family personally. In this way he made a pretty thorough canvass of every part of New England and New York State, of nearly every part of New Jersey and Pennsylvania, of the northern part of Ohio, and of some of the western cities.

After five years of these researches he published the second edition of the *Loomis Genealogy*, in which were given 8,686 names of persons that bore the Loomis name, descendants of Joseph Loomis in the male branches.

Five years later, in 1880, Professor Loomis printed in two additional volumes a provisional list of 19,000 descendants of Joseph Loomis in the female branches. Large as was this list, he did not regard it as more than a first outline of a census of the descendants of the original emigrant, and he hoped in the near future to publish an additional volume. For this he has left in manuscript many corrections and large additions that will be of use to the future Loomis Genealogist.

Am I tarrying too long upon the vacation work of Professor Loomis? If so, I plead on this occasion that among these direct descendants of Joseph Loomis there were enrolled more than 200 graduates of Yale College, and nearly 100 more of our graduates have married members of this numerous family.

Professor Loomis was doubtless more widely known as the author of mathematical text-books than as a worker in new fields in science. Shortly after coming to New York, he prepared a text-book in Algebra. The market was ready for

good book of this kind, and the work prepared for it was a good one. It was followed the next year by a Geometry. This was an attempt, and if judged by its reception and sale, it was a successful attempt to combine in a school-book the rigid demonstrations of Euclid with the courses of thought in Legendre and in modern science. The task is one of peculiar difficulty, as the existence and activities of the English Society for the Improvement of Geometric Teaching now for near twenty years illustrates. Other books followed the Geometry from year to year, the whole forming a connected series from Arithmetic upward, so that the list of his works finally numbered near twenty volumes. His experience in teaching, his rare skill in language, his clear conception of what was important, and his unwearied painstaking, combined to produce text-books which met the wants of teachers. About 600,000 volumes have been sold, benefiting the schools and colleges, and bringing to the author a liberal and well merited pecuniary return.

We ought not on this academic occasion to omit to speak of the teacher. College graduates who have been under his instruction will probably retain a more positive impression of the personal traits and the character of Professor Loomis than of most of their other teachers. His crisp sentences, lucid thought, exactness of language and steadiness of requirement, more than made up for any apparent coldness and real reserve. These characteristics of his riper years were peculiar to him from the beginning of his life as a teacher. During his tutorship he was thought to be strict as a disciplinarian, and this may have unfavorably affected his influence with some members of the class of 1837, of which he was tutor. It was not so with all of them. Some of you will recall what was said by a member of that class as he came to Commencement a few years since, occupying at the time the highest office which a lawyer in the line of his profession can in this country secure:—"If I have been successful in life," said Chief Justice Waite, "I owe that success to the influence of Tutor Loomis more than to any other cause whatever."

There was in Professor Loomis so much of reserve that to many persons he seemed cold and without interest in the lives

of others. But this was mainly due to appearances only. The tear would at times come unbidden to his eye. His correspondence with his classmates in the years immediately following graduation shows warm interest in all that concerned them. From Hudson he wrote often to Mr. Herrick, and complained much of isolation, but more especially of isolation from scientific companions and books.

In 1840 he married Miss Julia E. Upson, of Talmadge, Ohio, a lady about whom those who knew her have spoken to me only in terms of praise, and for whose memory Professor Loomis cherished a tender reverence. She died in 1854, leaving two sons. From this time Professor Loomis lived in apartments, surrounded by his books and devoted to his studies. His sons after passing their school and college days went to their own fields of work. During many years of his New Haven life he was unable to receive visitors in the evening. He made very few new friends, and one after another of his old ones passed away. To his work he was able to give undivided his time and his strength. His mind did not seem to require the excitement of social intercourse for its full and healthful activity. Isolated though he was there was in him no trace whatever of selfish or morbid feeling. In council his advice was always marked by his clear judgment of what was important, and at the same time what was practicable. Whatever he himself had the right to decide was promptly decided by a yes or a no. and few persons cared to question the finality of his decision. But when his colleagues, or others, had the right to decide he accepted their decision without questioning or subsequent murmur. Upon being told that his letters to Mr. Herrick had come to the College Library, and that he could, if he chose, examine them and see whether there were among them any which he would prefer not to leave in this *quasi* public place, he promptly replied: "No, I never wrote a letter which I should be ashamed to see published."

After coming to New York he had a generous income from his books, besides his salary as professor. The amount he saved from his income was carefully and prudently invested,

and before his death the savings with their accumulations were a large estate, how large only he and his banker knew.

One of his college classmates told me that Mr. Loomis left college with the definitely expressed purpose that the world should be better for his living in it. The central proposition in his Inaugural Address at Hudson in 1838 was: "That it is essential to the best interests of society that there should be a certain class of men devoted exclusively to the cultivation of abstract science without any regard to its practical applications; and consequently that such men instead of being a dead weight upon society are to be ranked among the greatest benefactors of their race." He chose this for his principal work for man, and he steadily kept to the chosen work. To establish an Astronomical Observatory had been through life a cherished object. He entered into and aided heartily the plans of Mr. Winchester, both before and after Mr. Winchester asked his Trustees to transfer his magnificent endowment to the University. Professor Loomis looked forward to a large institution in the future on the observatory site. To endow this public service, after making liberal provision for his two sons, he bequeathed his estate. The income from more than $300,000 will eventually be available to continue the work of his life. With clear judgment of what was most important he limited the use of that income to the payment of salaries of persons whose time should be exclusively devoted to the making of observations for the promotion of the science of astronomy, or to the reduction of astronomical observations, and to defraying the expenses of publication. He knew that if he provided observers, other benefactors would furnish buildings, and instruments, and the costs of supervision and maintenance.

A university has an organic life, with its past and its future. The wealth of a university consists mainly in its men;—not so much in those men who are its active members now, as in those who have lived themselves into its life in the past, and have made it a home of scholarship, of truth and of devotion to duty, a place fit for the development of the nobler elements of character. The life and work of Elias Loomis form no mean portion of the wealth of Yale University.

Art. LIV.—*The Magnetic Field in the Jefferson Physical Laboratory.* Part II; by R. W. Willson.

In the February number of this Journal I have given an account of some observations made upon the variations of the Horizontal Intensity in different parts of the Jefferson Physical Laboratory in 1886–7, and upon the disturbance in the magnetic field produced by the presence of iron steam pipes and other iron masses. I have recently received a copy of the dissertation of Dr. Gustav Rasch of Aix-la-Chapelle* giving the results of similar observations upon the effect of the heating apparatus in the Physical Laboratory at Würzburg and of passing railway trains, etc.

During the past summer an iron water-pipe six inches in diameter was laid for some hundreds of feet, nearly parallel with the west wall of the Jefferson Laboratory and passing it at a distance of about twenty feet. The question was raised whether this would produce any serious change in the magnetic conditions previously observed in the building, and at the request of the Director, Professor Trowbridge, I have made a re-examination of the variations of the Horizontal Intensity at the points observed in 1887. A further interest in the results lies in the fact that since the former observations were made both the stove and iron table top, to which I attributed certain disturbances, have been removed, and it may now be seen whether the disturbances have disappeared with their assumed causes. Whether there has been any change in the absolute value of H, about 0·170 C. G. S. units, I have not attempted to determine.

Rooms 12 and 17, were not included in the observations on account of the great variations caused by the proximity of the steam-pipes at A, B, C, F, near the east wall (fig. 4).

The same instrument was used and mounted upon the same stand, a small high table carrying the variometer, five feet from the floor and resting on three very easy casters. Attached to the stand at about two and a half feet from the floor is a magnetometer with mirror and scale which serves for the rapid orientation of the stand at each new station. The distance between the variometer and magnetometer is such that neither has any appreciable influence upon the readings of the other, and at no point of observation was their difference of meridian (from local disturbances, such as proximity of the magnetometer to the piers) sufficient to cause an error so great as $\frac{1}{20.000}$ in the concluded value of H.

* Magnetische Untersuchungen. Würzburg, 1888.

It will be remembered that the plane of observation was originally fixed at five feet from the floor to avoid any possible disturbance due to the brick-work of the piers. A few preliminary observations had seemed to show such an effect, amounting to about 1–1000 H, in the case of one pier, when the instrument was very near the brick-work; while observations taken at various points upon one of the piers in room 17 showed no apparent magnetic effect comparable with that due

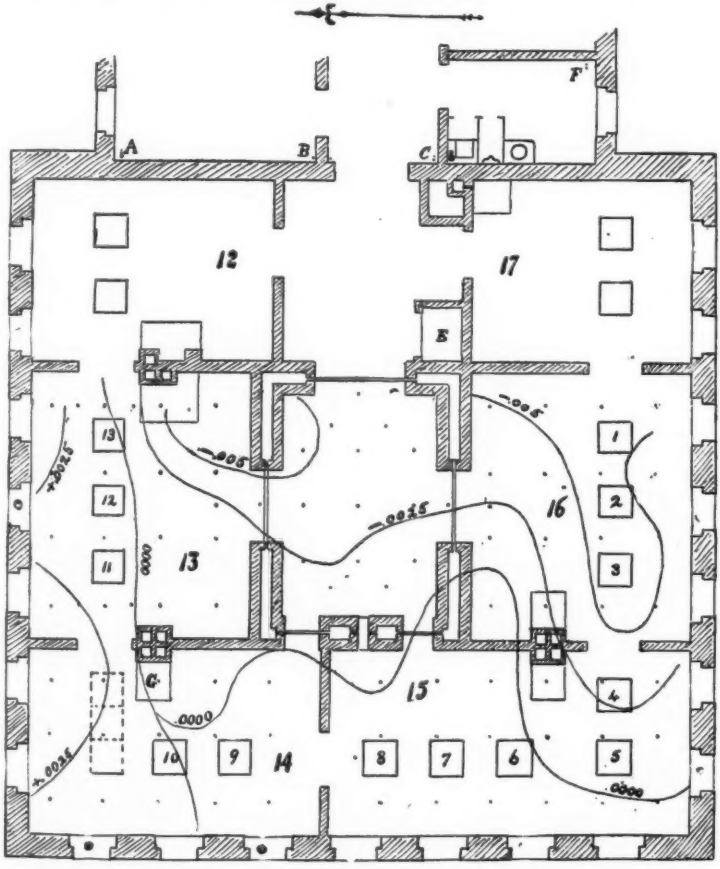


Fig. 4. Plan of west wing of the Jefferson Physical Laboratory, with lines of equal directive force in plane 5 feet above first floor. Scale 16 feet to the inch.

to the steam-pipes. Recent observations show that this pier somewhat resembles pier 4, hereinafter discussed, and was unfortunately selected as a test.

The observations upon the magnetic declination at various levels in the elevator shaft, described on page 90, were originally made in order to see if any considerable amount of free magnetism was present in the walls of the central tower. The results showed a far greater effect due to the steam-pipes than any that could be ascribed to the brick-work, and it was this which first led to a careful examination of the pipes and a just estimation of their effect upon the magnetic field. These results are here noted to explain why the very considerable

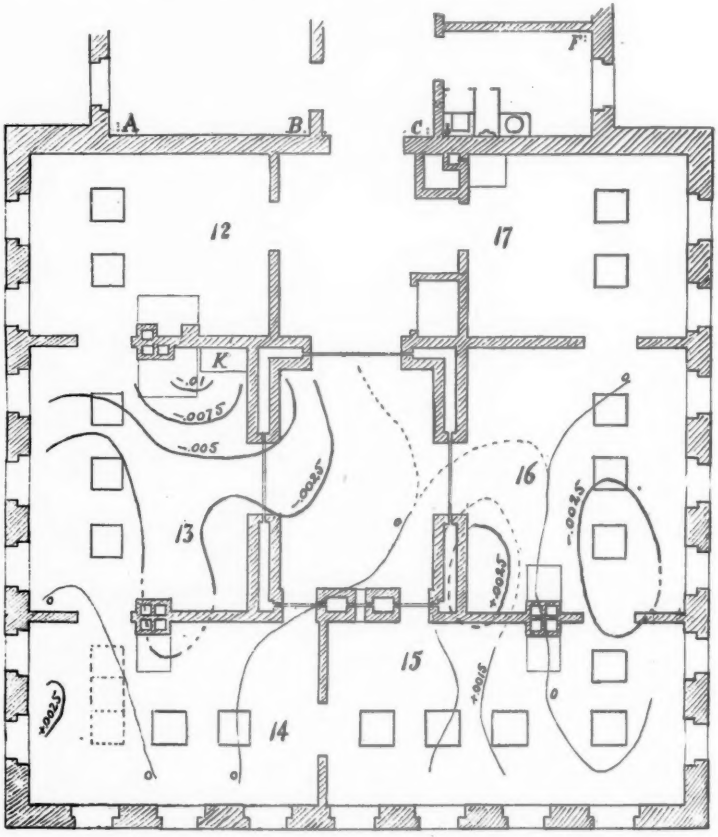


Fig. 5. Plan of west wing of Jefferson Physical Laboratory, with lines showing disturbances of the earth's directive force due to causes other than presence of steam-pipes shown at A, B, C and F.
K. Soap-stone sink.
Scale sixteen feet to the inch.

effect due to the general magnetization of the bricks, soon to be recorded, should have escaped even a very superficial examination.

The result of the general survey undertaken to determine what change in the field may have been produced by the laying of the water-pipe mentioned above is exhibited in figs. 4 and 5.

Fig. 4 gives the lines of equal horizontal intensity recently determined and is to be compared with fig. 1, p. 88. These lines connect points at which the horizontal intensity is the same, the values at points in adjacent lines differing by ·0025 H. It is evident that there is no change in the general character of the field except that due to the removal of the stove above G. This will be more evident on consulting fig. 5, which gives the results obtained by correcting the observed values for the disturbance due to the steam-pipes at A, B, C and F by the method explained on page 91 (fig. 5 may be compared with fig. 3, p. 92).

The disturbance in room 13 being unchanged although the iron table top to which it was ascribed has been removed, some other cause must be sought for this disturbance.

The observations upon which the system of lines depend were made at points distant five feet from each other and only the general features of the system can be thus determined. In order to settle definitely the cause of the disturbance in room 13, observations have recently been made at distances of one foot apart in the eastern part of the room, and the lines of equal directive force thus much more accurately drawn. As the object was simply to determine the position of the disturbing body, the plane five feet from the floor was abandoned in these observations, and the arrangement adopted which had been used in the examination of the piers, which greatly lessens the labor and increases the accuracy of observations made at points very near together. The results of this examination pointed unmistakably to a soap-stone sink, shown at K, fig. 5, as the *main* cause of the disturbance. (This sink showed a considerable free south magnetism on its upper surface, tending to decrease H at points north and above; some further account of this will be given later.)

The only disturbances remaining unaccounted for are that in room 15–16 and that in room 14; which I now believe to be almost entirely due to magnetic action of the bricks of the piers and walls of the building itself. If this is the case, the whole system of lines of figs. 4 and 5 must be looked upon as giving only the most prominent characteristics* of the field,

* Compare with fig. 10, which gives a portion of the field more in detail, but for a different plane.

since many of the points observed are so near the piers as to be unduly affected by their presence. As the magnetic effect of the mass of the building upon the Horizontal Intensity at any point is too complex to admit of estimation, I have confined myself principally to an investigation of the effect of the piers.

To facilitate these observations a board 28 feet long, and 8 inches wide was carefully smoothed and brought to a straight edge and wooden horses, put together with copper nails, were prepared of just the height of the piers; a sliding piece 15 inches long with a guide bearing upon the edge of the board, carried the variometer with its needle in a plane seven inches above the top of the piers and 3 feet 3 inches above the floor.

The long board being brought into position, supported by the piers or horses, the variation at different points could be rapidly observed without any sacrifice in point of accuracy, the instrument being slid from one point to another with very slight derangement in level and azimuth, so that the latter adjustment was made once for all while the former was very quickly accomplished. The changes of temperature are also less troublesome factors than when the observations extend over considerable periods of time. Variations of the horizontal intensity during the observations have usually been determined and corrected for by occasional observations at the same reference point.

The piers consist of rectangular columns of brickwork laid in Portland cement. They are 3 feet by 2 feet at the base, tapering to 2 feet square at the first floor, above which they rise 2 feet 4 inches, and are capped by slabs of blue stone 3 feet square and 4 inches thick. The foundations are 5 feet below the basement floor and the total height of the column is about 18 feet. As the building faces within $2\frac{1}{2}$ degrees of the magnetic South, and as the sides of the piers are parallel to the walls of the building, it will be sufficiently accurate in describing their magnetic effect to speak of either as if exactly oriented.

If the brick of which the piers are made contains magnetic material we should expect to find indications of a magnetic distribution depending upon the inductive action of the earth and the form and position of the piers, independent of any permanent magnetism existing in the bricks previous to their being placed in their present places, and which, on account of its random distribution, in so large a number of bricks, would have no effect except in causing small very local disturbances easily recognizable as such.

The effect of the earth's induction upon the piers would produce, on the whole, free south magnetism on the upper

surface of each pier, and owing to the length of the piers and the very considerable dip, 72 degrees,* the distribution would

Dist. from south wall.	Nov. 22.	Nov. 21.	Nov. 23.	East Edge.	West Edge.	
4	+0003	−0001	.....	+0001	0000	
4½	+0012	+0009	.....	+0005	.....	
5	+0029	+0025	.....	+0011	+0014	
5½	+0034	+0029	.....	+0009	+0018	
6	+0008	+0004	.....	−0008	+0003	
6½	−0020	−0027	.....	−0025	−0024	over pier 5.
7	−0050	−0055	.....	−0032	−0032	
7½	−0066	−0067	.....	−0040	−0037	
8	−0051	−0053	.....	−0033	−0036	
8½	−0034	−0033	.....	.....	.....	
9	−0021	−0023	.....	−0015	−0017	
9½	−0015	−0014	.....	.....	.....	
10	−0010	−0009	.....	−0008	−0006	
10½	−0007	−0006	.....	.....	.....	
11	−0004	−0002	.....	−0003	−0009	
11½	+0001	+0002	.....	.....	.....	
12	+0004	+0007	.....	+0006	+0002	
12½	+0008	+0013	.....	.....	.....	
13	+0012	+0016	.....	+0013	+0008	
13½	+0017	+0021	.....	.....	.....	
14	+0022	+0024	+0020	+0012	+0012	
14½	+0014	+0018	+0013	.....	.....	
15	−0001	.....	0000	0000	+0001	
15½	−0005	.....	−0008	.....	.....	over pier 6.
16	−0001	.....	+0001	+0006	−0001	
16½	−0004	.....	−0003	.....	.....	
17	−0010	.....	−0010	+0001	−0005	
17½	−0009	.....	−0008	.....	.....	
18	−0004	.....	−0001	+0006	−0001	
18½	+0002	.....	+0007	.....	.....	
19	+0009	.....	+0015	+0014	+0007	
19½	+0017	.....	+0021	.....	.....	
20	+0022	.....	+0025	+0023	+0015	
20½	+0023	.....	+0027	.....	.....	
21	+0019	.....	+0023	+0011	+0009	over pier 7.
21½	+0004	.....	+0008	.....	.....	
22	−0008	.....	−0006	+0004	+0010	
22½	−0009	.....	−0005	.....	.....	
23	−0002	.....	+0002	+0009	+0007	
23½	+0005	.....	.....	.....	.....	
24	+0011	.....	.....	+0017	+0017	
24½	+0018	.....	.....	.....	.....	
25	+0024	.....	.....	+0023	+0027	
25½	+0035	.....	.....	.....	.....	
26	+0051	.....	.....	.....	.....	
26½	+0069	.....	.....	.....	.....	
27	+0060	.....	.....	.....	.....	
27½	+0021	.....	.....	.....	.....	over pier 8.
28	−0008	.....	.....	.....	.....	
28½	−0006	.....	.....	.....	.....	
29	+0014	.....	.....	.....	.....	
29½	+0030	.....	.....	.....	.....	
30	+0039	.....	.....	.....	.....	
30½	+0044	.....	.....	.....	.....	

* Erroneously given in my last paper as 60 degrees.

be nearly uniform. The result would be that at points north of the center the field would be weakened and at points south strengthened, while in a line east and west through the center of the pier the field would be undisturbed by its presence.

The preceding table shows the variations of the Horizontal Force actually observed along a horizontal line passing 7 inches above the centers and edges of the piers 5, 6, 7, 8 in room 15, fig. 4.

Column 1 gives the distance of the point of observation from the south wall. Columns 2, 3 and 4 the corresponding difference in decimal parts of H, from its value assumed as normal in those parts of the room farthest removed from the influence of the piers. Columns 5 and 6 give the corresponding values on parallel lines 14 inches east and west of the central line. Columns 3 and 4 are introduced to furnish a means of judging of the accuracy of the individual observations, each of which rests upon *a single* reading of the instrument in each of the positions, N. pole east and N. pole west.

Although the differences on different dates amount in the maximum to ·0007 H, owing to uncertainty in the diurnal variation of H, which has been assumed to be uniform during the time of observation, it will be noticed that the difference between consecutive points (upon which the important features of the disturbance depend) as observed on various dates, is the same for 32 out of 39 points, within ·0002 H, which is practical identity, since any observation may be in error in either direction by ·0001 H. In four cases the difference is ·0003 H, in two cases ·0004 H and in one case ·0005 H. This is remarkable testimony to the accuracy of the instrument when it is remembered that each determination required but little over two minutes for its completion.*

The results of column 1 are best exhibited to the eye by fig. 6, in which the abscissas represent distances from the south wall in feet while the ordinates give the corresponding differences from the normal undisturbed value of H for the whole room. The places of the piers are as indicated below.

It appears that in passing from south to north the value of H increases as we approach the pier 5 to a maximum almost exactly over the edge of the brick-work and six inches inside of the bluestone, then rapidly decreases to a minimum almost exactly over the northern edge of the brick-work, from which it increases, reaching the average value for the room at a point about half way to the next pier. Beyond this it still increases to a maximum over the edge of pier 6 and follows the same

* For a detailed account of the method of observation see the paper by F. Kohlrausch, Wied. Ann., vol. xix, p. 130. As my instrument was adjusted a difference of one division in the reading of $n_1 - n_2$ corresponds to ·00025 H.

general course for that and for each of the other piers. The curves corresponding to the values in columns 4 and 5, observed nearly over the eastern and western edges of the brickwork, show maxima and minima at the same points but of about half the values reached on the center lines, the values being very nearly the same for each edge.

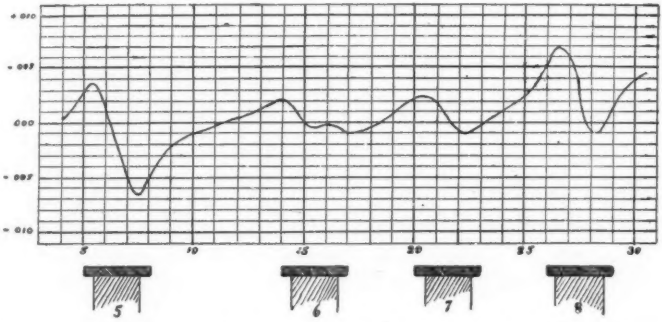


Fig. 6. Variations of the Horizontal Intensity in a line seven inches above piers.

The general form of the curve is accounted for by the assumption that free south magnetism is distributed nearly uniformly over the upper surface of each of the piers, strengthening the field on the south side and weakening it on the north as before described, while over the center the Horizontal Force has nearly its normal value.

The fact that the values of the maxima over the edges are about half those in the central line strengthens this assumption of a uniform distribution of the magnetism over the surface, since, if the pier be supposed divided by a vertical plane passed meridionally through the center, the half of the pier farthest removed contributes but little to the disturbance over the edge, while if transferred parallel to itself so that the two edges coincide, each half would be similarly situated with respect to the points observed, and the effect would be doubled and should obviously give the same value of the disturbance as that actually observed on the central line.

The double maximum observed in the case of pier 6 appears to be owing to an irregularity in the distribution of the magnetism, perhaps due to a single brick or bricks near the surface of the pier possessing permanent magnetism, not produced by the induction of the earth upon it in its present position.

Such permanent polarity has been observed in varying degree in many bricks and portions of bricks of the same manu-

facture. With this exception the magnetism shown by the piers is exactly what might be expected to result from the effect of the earth's nearly vertical induction upon a mass containing a relatively small amount of magnetic matter in the form of isolated particles, disseminated through a non-magnetic shaft nearly 20 feet high and of relatively small diameter.

The nearly uniform distribution of the magnetism is further confirmed by observations of the other piers, the results of which are shown in figs. 7 and 9.

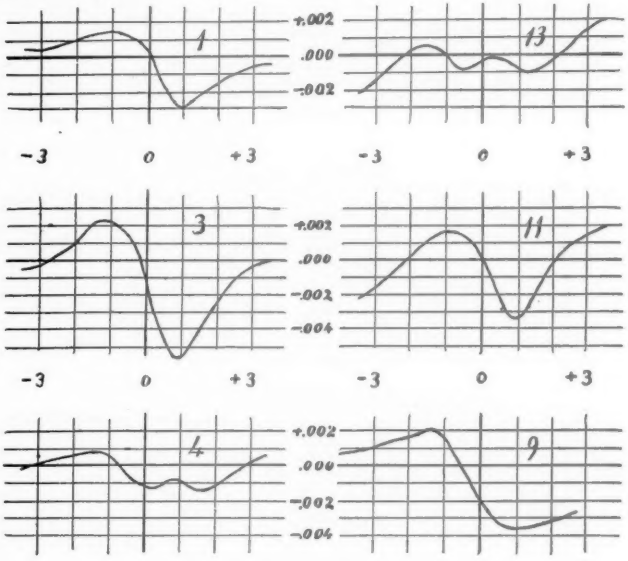


Fig. 7. Variations of the horizontal intensity in a line seven inches above piers.

In fig. 7 the variations of the horizontal force along the central line are shown for piers 1, 3, 4, 9, 11, 13. The abscissas give the distance in feet from the center of the pier in each case, positive toward the North, and the ordinates in the same manner as before give the variations of H from its normal value, which is here assumed to be the mean of observations North and South at a distance of 3 feet from the center.

Let $2l$ be the length in centimeters of the side of a square pier, σ the density per sq. cm. of the magnetism uniformly distributed over its upper surface. Then a unit pole h cm. above the pier, and in its meridian plane at a distance x_0 cm. from the axis, is urged horizontally toward the axis by a force in C. G. S. units

$$F=2\sigma \log_e \frac{(l+\sqrt{(x_0-l)^2+h^2+l^2})\ ((x_0+l)^2+h^2)}{(l+\sqrt{(x_0+l)^2+h^2+l^2})\ ((x_0-l)^2+h^2)}.$$

For our piers $l=30^{cm}$, and $h=28^{cm}$.

The value of F for different values of x_0 computed from the above expression is given in the following table:

x_0	F.	x_0	F.
0 cm	0·000 σ	30cm	2·698 σ
5	0·570 σ	35	2·833 σ
10	1·114 σ	40	2·856 σ
15	1·626 σ	45	2·796 σ
20	2·080 σ	50	2·682 σ
25	2·446 σ	60	2·390 σ

Plotting the coefficients of σ we obtain a curve very similar to that of pier 5, fig. 6, showing that the assumption of uniform distribution agrees well with the observed values.

The maximum observed value is about ·005 H=·00085 absolute units and corresponds to the computed value 2·8 σ; hence σ=·0003 and the total amount of free magnetism on the surface of the piers, 3600 sq. cm., is 1·08 C. G. S. units.

PIER 5.

Distance North of Center. (inches.)	Distance East of Center (inches).							
	−14	−10	−6	−2	+2	+6	+10	+14
+18	−0012	−0023	−0023	−0026	−0026	−0021	−0020	−0016
+14	−0018	−0029	−0033	−0038	−0037	−0032	−0031	−0019
+10	−0016	−0026	−0034	−0038	−0038	−0034	−0029	−0024
+ 6	−0012	−0022	−0028	−0026	−0028	−0024	−0021	−0013
+ 2	−0004	−0008	−0009	−0007	−0011	−0007	−0010	−0009
− 2	+0010	+0008	+0011	+0012	+0007	+0006	+0002	−0001
− 6	+0025	+0025	+0031	+0033	+0029	+0025	+0017	+0011
−10	+0038	+0042	+0049	+0052	+0051	+0045	+0037	+0022
−14	+0042	+0048	+0055	+0057	+0059	+0052	+0046	+0026
−18	+0036	+0041	+0047	+0048	+0049	+0046	+0043	+0027

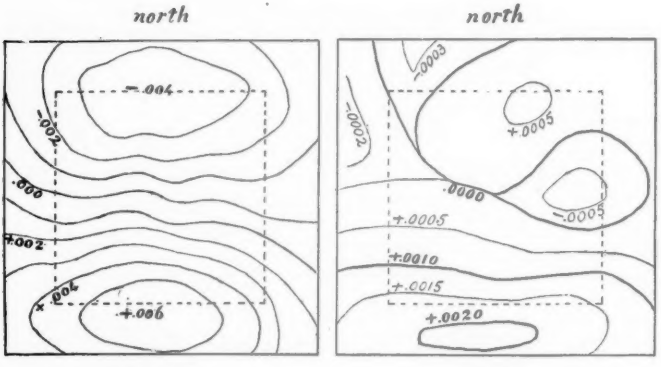
PIER 4.

Distance North of Center. (inches.)	Distance East of Center (inches).					
	−15	−9	−3	+3	+9	+15
+18	−·00005	−00040	+·00010	−·00005	+·00020	+00025
12	−·00025	−00020	+·00030	+·00065	+·00030	+00020
6	−·00025	00000	+·00040	+·00040	−·00020	+00010
0	+·00010	+00020	+·00020	−·00020	−·00090	−00020
− 6	+·00080	+00075	+·00060	+·00050	+·00050	+00040
12	+·00160	+00170	+·00160	+·00160	+·00170	+00130
18	+·00170	+00190	+·00195	+·00190	+·00155	+00140

The length of the pier being about 6 meters, this corresponds to a magnetic moment of 6500 C. G. S. units or rather more than that which may be readily given to a hard steel magnet of 1 sq. cm. section and 20 cm. long.

Piers 1, 2, 3, 5, 7, 8, 9, 11, 12, figs. 6, 7 and 9 show variations nearly as described for a typical pier; while 4 and 13 show the same irregularity as 6*. I may here note that the pier in room 17, which was superficially examined in 1887 for the purpose of detecting local influences was of this class, the variation over a large part of its surface being very small.

The nature of this deviation from this normal type is made more striking by comparison of the adjacent piers 4 and 5, the former presenting the case of least and the latter of greatest local effect of piers. The variations of H from its value at the center are given in the preceding tables, and fig. 8 shows the lines of equal horizontal force in a plane seven inches above each pier. The field above 4 although the extreme variation amounts to but ·0025 H, indicates a distribution of magnetism far from uniform. The existence near the northeast corner of free north magnetism would account for the observed variations. In the case of pier 5 the effect of the pier, though large, is quite symmetrical, indicating a very uniform distribution.



Pier 5. Pier 4.

Fig. 8. Lines of equal directive force in a plane seven inches above piers 4 and 5.

The magnitude of the disturbance is noteworthy. Above pier 5, for instance, the Horizontal Force at the two edges varies by one per cent, while a change of one tenth of one per cent is caused by passing over two inches near the center, so

* Pier No. 10 has been omitted being covered with a heavy stone. Piers in rooms 11 and 17 are not included for reasons before given.

that the position of an instrument must be determined with considerable precision to ensure even ordinary accuracy. Moreover all of the points observed are distant at least 11 inches from the nearest brick-work. It is plain then that the observations made 5 feet from the floor and 2 feet 8 inches above the brick-work of the piers are by no means unaffected by the presence of the latter.

The effect of the walls too may extend to points at some distance. The magnetism due to the earth's induction pro-

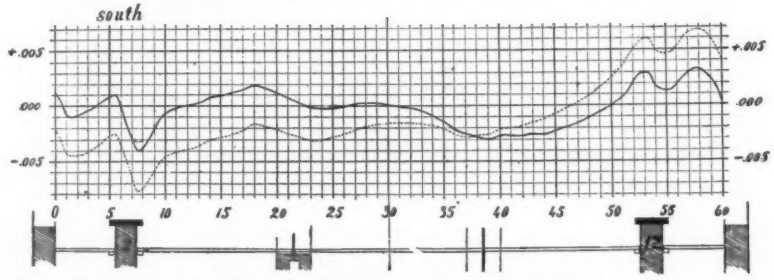


Fig. 9. Variations of the Horizontal Intensity on a line seven inches above piers 2 and 12.

duces disturbances in the neighborhood of openings in the brick-work, such as doors and windows, where free magnetism appears, and the local effect of permanent magnetism in the single bricks can be in many places detected. The first point appears in the observations represented in fig. 9 which shows the variations along a line passing above the piers 2 and 12 and through the center of the wing.

The dotted curve gives in the same manner as before the variations of H from its normal value at the center of the wing, the position of the walls, piers and door-ways being indicated as on fig. 6. The line of observation passes 11 inches above the brick-work of the piers, 12 inches above that of the window sills, and $3\frac{1}{2}$ feet above the lower brick-work of the door opening in the tower wall. The door openings are 10 feet high and the instrument is therefore much nearer to the bricks below than to those above. The general increase of H toward the north shown in the dotted curve is due to the influence of the iron steam-pipes. Correcting the observed values for this effect the full line curve is obtained. Both curves show south magnetism in the vicinity of the walls and piers, the earth's induction producing free south magnetism in the lower surfaces of the window and door openings through which the line of observation passes. This results in a strengthening of the field on the south in the immediate

vicinity of the openings and a weakening on the north, as in the case of the piers. (The point of maximum disturbance is

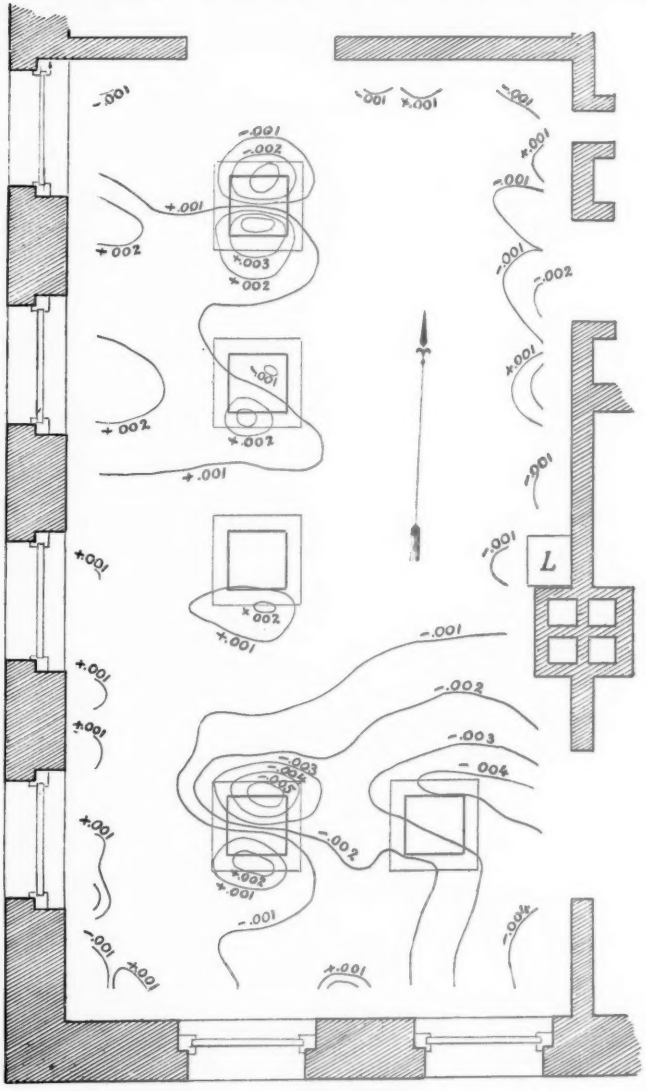


Fig. 10. Lines of equal directive force in room 15, plane seven inches above piers. Scale, six feet to the inch.

not over the edge of the brick-work as in the case of the piers, owing to the different form of the surface, and in the case of the door, to the greater distance of the plane of observation.) The absence of local disturbance in the north doorway of the tower is due to the fact that there is on that side a corresponding doorway in the basement, and the opening in the brick-work extends to the ground level.

The amount of irregular disturbance arising from nearness to walls is shown in fig. 10, which gives the lines of equal directive force in room 15 in a plane 7 inches above the piers, plotted from a very careful survey in which observations were made at points one foot apart over the whole room.

This shows the same general features as the former survey 5 feet above the floor.

This detailed observation, however, enabling a much more accurate determination of the lines brings out very clearly the connection of the piers with these disturbances.

The effect of the individual bricks is so great when the points are within 6 inches of the wall that I have only continued the lines within one foot of the bricks, although many observations were made within that limit to determine more accurately the position of the lines. It is worthy of notice that no considerable disturbance is produced by the small soap-stone sink near the chimney at L.

The normal value assumed is the mean of the values observed at 96 points taken in a parallelogram 15 feet $\times$ 5 feet about the arrow, fig. 10, no point being less than three feet removed from the nearest bricks.

Within this space the deviations though less than ·001 H from the mean are plainly discriminated by the variometer, and it may be fairly said that there is no point in the room where the magnetic effects of the brick-work is not an easily measurable quantity.

It is hardly worth while to multiply observations or to treat of such points as the effect of change of temperature, since the magnetic effect of the bricks is so great. A few facts are, however, of interest. Bricks similar to those used in the Laboratory Building have been found to be in various degrees permanently magnetic, and to show the alterations in their temporary magnetism produced by change of position with respect to the earth's field, two or three specimens of brick from other sources show magnetic effects comparable with these.

Portions chipped from the piers and crushed to coarse powder delivered to a 2 oz. magnet many magnetic particles, which when examined under a microscope were seen to contain among their number octahedra of magnetite. Magnetic par-

ticles were separated in the same manner from the cement, as well as from the clay of the brick-yard where the bricks were made.

Far more striking results were obtained on examining the soap-stone sink which is connected with the disturbance in room 13, and which shows upon the upper surface and edges of its slabs free south magnetism of sufficient amount to deflect a compass needle several degrees when brought within an inch of its mass.

Sixteen grams of dust scraped with glass from the under side of the base gave 1 gram of dark *strongly* magnetic particles consisting mainly of magnetite in octahedra up to 1-2^{mm} in diameter, which were disseminated through the mass with considerable uniformity. Pencils cut from a similar slab and hung by a thread were strongly attracted by a magnet, though they received no permanent polarity. A chip of the same weighing over one third of a gram was lifted bodily by a one pound magnet with poles approaching each other within $\frac{1}{8}$ of an inch.

I am not aware that any observation has been previously made of so great a disturbance of the magnetic field from brick-work. In the magnetic observatory at Würzburg the brick for which was selected with great care, a variation of ·00025 H has been noted.* Lamont† remarks upon a difference of 2′ 18″ in declination and 0·00014 in the value of H between observations made in the open field near the observatory (Munich) and upon an "aus Backsteinen und hydraulischen Kalk, ausserdem Starke Messingtheile enthaltenden Pfeiler" in the building itself. This discrepancy he does not appear to have investigated further.

It is possible that the Cambridge brick, of which the Jefferson Laboratory is built, contains an unusual amount of magnetic oxide, but it is a fact not to be slighted by those engaged in magnetic work that bricks, without special examination, cannot be assumed to have an insignificant magnetic effect.

In fact, I incline to the belief that in general it is safer to make exclusive use of wood for buildings and piers intended for refined magnetic measurements.

Jefferson Physical Laboratory.

* F. Kohlrausch, Wied. Ann., vol. xix, p. 142, 1883.

† Abhandl. d. k. bayr. Akad. d. Wiss.; Math.-Phys. Kl., v, p. 24, 1847.

ART. LV.—*The Electrical Resistance of the Alloys of Ferro-Manganese and Copper;* (From determinations made by Mr. B. H. Blood); by EDWARD L. NICHOLS.

[Contributions from the Physical Laboratory of Cornell University, No. 6.]

IN the selection of a material for standards of electrical resistance, the influence of temperature upon the conductivity of the wire to be used in their construction is a factor of prime importance. Since the report of the British Association Committee (1867) on electrical standards, no great progress has been made in this matter. The manufacturers of German silver and of similar alloys have, it is true, succeeded in reducing considerably the temperature-coefficients of their metals; so that it is now possible to obtain wires the resistance of which changes less than two hundredths of one per cent per degree Centigrade. Such a variation is, however, by no means negligible in operations of precision; and the coefficient of different wires, even when made from the same metal, vary greatly. In a single resistance box, as has been shown by Professor Anthony, one may have coils which are well adjusted at some one temperature but to which, no single temperature-correction will apply.* On this and on many other accounts, the discovery of an alloy, the resistance of which is unaffected by temperature is a matter of some importance.

In 1888 patents were granted by the United States government, for two new alloys to be used in the construction of resistance coils.† The properties claimed for these alloys were so remarkable—complete freedom from change of resistance upon heating in the one case and a decrease of resistance with rise of temperature, in the other—that in the absence of more complete data concerning them than are contained in the patent office specifications, it seemed to me a matter of some importance to subject them to a detailed experimental investigation.

The necessary experiments were undertaken at my suggestion by Mr. B. H. Blood, and it is upon his results that the following statements are based.‡

* W. A. Anthony: On the Differing Temperature Coefficients of the Different Coils of a fine Rheostat. Transactions of the American Institute of Electrical Engineers, vol. iv, p. 137.

† See Edward Weston, U. S. patents, Nos. 381,304 and 381,305; Specifications and Drawings of Patents, April 17, 1888, p. 1507. Also Official Gazette of the U. S. Patent Office, vol. xliv, p. 339.

‡ B. H. Blood: Temperature Coefficients of Ferro-manganese-Copper Alloys, Thesis (in MS.); Library of Cornell University. 1889.

The materials used in Mr. Blood's investigation were the pure copper of commerce and "ferro-manganese" containing seventy-nine per cent of manganese. These were fused together in a small carbon crucible, the sides of which were lined with porcelain. The mixture was placed in the bottom of the crucible in contact with the carbon, which was connected with the positive pole of a storage battery. A carbon pencil, connected with the other pole of the battery, was then brought into electrical contact with the charge from above, and quickly withdrawn to a distance of a few millimeters. Under the action of the arc thus formed, a charge weighing three or four grams was completely fused in about thirty seconds, without any considerable oxidation of the metals. The irregular ingot thus formed was afterward rendered more nearly homogeneous by being re-melted in the voltaic arc, for which purpose it was removed from the crucible and placed upon a metal plate. The globule of metal thus obtained was rolled into a thin strip, from which was cut a piece fifteen centimeters long and of such width as to give a resistance of about eight-tenths of an ohm.

The method of measurement employed was as follows: The strip of alloy to be tested was connected in series with a comparison standard, the resistance of the two being approximately equal. These, together with a third resistance of about one hundred and fifty ohms, formed the outer closed circuit of a single gravity cell. "Potential wires" from the terminals of the strip of alloy and of the standard, were joined to a switch of such construction that a mirror galvanometer could be connected in shunt with either. The galvanometer had a resistance of two thousand ohms. A comparison of deflections when the galvanometer was shunted around the resistance standard, and around the test piece, afforded data for the calculation of the resistance of the latter.

This method is exceedingly sensitive, and when properly conducted, it is capable of a high degree of accuracy. In the experiments under consideration, a check upon errors arising from fluctuations in the amount of current traversing the test piece and from changes in the constant of the galvanometer, was obtained by ever repeated reference to the indications of the latter when connected with the terminals of the standard.

In order to relieve the observer of the necessity of maintaining the reference standard at a constant temperature, or of applying temperature-corrections to the results obtained, a compensated carbon standard, of the type recently described by the writer, was constructed.* The resistance of this stand-

* On Compensated Resistance Standards; Transactions of the American Institute of Electrical Engineers, vol. v, No. 10, 1888.

ard was 0·770 ohms; and its temperature-coefficient was about ·000010 per degree Centigrade.

The test piece, enclosed in a U-shaped tube of glass, was placed in an oil bath and alternately heated to 100° C. and cooled to 20°. The reference standard was kept at the room temperature. Its changes of resistance were regarded as negligible.

The application of the method just described, to a number of ferro-manganese-copper alloys, brought to light a remarkable and very troublesome property of this class of metals. It was found that they decreased in resistance each time that they were subjected to a change of temperature, even through the small range made use of in the attempt to determine their temperature-coefficients. The character of these changes can best be illustrated by quoting a series of measurements to which one of the alloys was subjected. An alloy containing 80·82 per cent of copper and 19·12 per cent of ferro-manganese, had been hard drawn in the process of obtaining a strip suitable for measurement. Its specific resistance at 20°, referred to pure copper as unity, was 30·38. It was repeatedly heated to 100° and cooled to 20° with the following result:

TABLE I.

Effect of repeated heating and cooling upon the resistance of Alloy No. 6, (hard drawn).

Observation.	Temperature.	Specific resistance.	Relative resistance.
1	20°	30·380	1·0000
2	100	30·186	·99331
3	20	30 163	·99287
4	100	30·151	·99255
5	20	30·138	·99202
6	100	30·121	·99180
7	20	30·118	·99134
8	100	30·118	·99134
9	20	30·105	·99093
10	100	30.099	·99072
11	20	30·092	·99051
12	100	30·104	·99092
13	20	30·079	·99007
14	100	30·104	·99092
15	20	30·072	·98985

We have, in the case of this alloy, a substance which increases in conductivity each time it is heated and cooled through the small range of 80°, the change in resistance diminishing in amount with each operation, but still perceptible at the end of the seventh cycle. At the same time a positive temperature-coefficient is being developed, which continues to increase as the heating and cooling process is repeated.

After being heated to 100° seven times, with the result shown in Table I, the alloy was raised to a red heat. Its tem-

perature-coefficient was then redetermined with the result shown in the following table:

TABLE II.

Resistance and temperature coefficient of Alloy No. 8, (*after annealing at a red heat*).

Temperature.	Specific resistance. (At 20°)	Specific resistance. (At 100°)	Coefficient.
20°	28·478	------	--------
100	------	28·610	+·000052
20	28·446	------	---- ----
100	------	28·597	--------
20	28·440	------	+·000052

The effect of repeated annealing upon the resistance and coefficient of these alloys, is still more strikingly exhibited in the behavior of a specimen containing a larger proportion of ferro-manganese. The alloy in question consisted of 70·65 parts of copper and 29·35 parts of ferro-maganese. After being brought into a condition of stability, such that further heating and cooling through a range of eighty degrees had but little permanent effect upon its conductivity, it still showed, when hard drawn, an appreciable negative coefficient. It was then annealed three times at a red heat; specific resistance and coefficient being determined for the range 20° to 100°, after each annealing. The results are given in Table III.

TABLE III.

Effect of repeated annealing upon Alloy No. 11.

Condition.	Specific resistance. 20°	Specific resistance. 100°	Specific resistance. 20°	Coefficient.
Rather hard	46·10	45·99	46·09	—·000024
Once annealed	45·10	45·18	45·09	+·000021
Twice annealed	44·07	44·33	44·06	+·000068
Thrice annealed	42·76	43·58	42·74	+·000192

This metal possessed very nearly indeed the composition for which, in the patent specifications already referred to, the remarkable property of decreasing resistance with rise of temperature was claimed; which claim is substantiated, so far as the hard-drawn alloy is concerned. It will be seen that the coefficient depends upon the temper of the metal, and that it would probably be an easy matter to bring the latter into such a state that the change of resistance, which is, in all conditions of the alloy, very much smaller than in any other of which we have definite data, would be too small to be detected.

It appears, moreover, that the conductivity of this alloy was increased about 2 per cent by each successive annealing at a red heat, and that even after being thus annealed three times, it was subject to a further slight but measurable increase of conductivity, amounting to at least ·02 per cent, when subsequently heated to 100° and cooled to 20°.

The influence of temper upon the temperature-coefficient of a number of similar alloys was investigated by the method just described. The alloys showed, when hard rolled, a coefficient very near to zero, sometimes positive, sometimes negative. After annealing at 300° to 400° a well defined negative coefficient, after annealing at a red heat, a still larger positive coefficient, was developed. It was found that the positive coefficient produced by annealing, could be reduced again by rolling the alloy. Table IV shows the character of the results obtained. They were verified in every essential detail by frequent repetitions.

TABLE IV.

Influence of alternate annealing and hardening upon the temperature-coefficient.

Alloy No. 7. (Copper, 80·40%, Ferro-manganese, 19·60%).

Condition of the alloy.	Coefficient (20°—100°).
Hard	+·000022
Partially annealed	—·000032
Thoroughly annealed	+·000066
Re-rolled (hard)	+·000021
Again annealed	+·000045

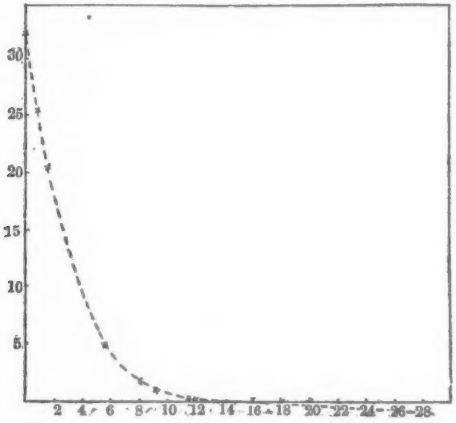
To determine the relation of the composition of these alloys to their temperature-coefficients, Mr. Blood tested twelve specimens, in which the amount of copper ranged from 70 per cent to 99·5 per cent, and also the copper itself from which the alloys were made. The percentage of copper present in each test-piece was determined to within one hundredth of one per cent, by the method of electro-deposition. The results of these determinations are incorporated in Table V.

TABLE V.

Percentage of copper.	Percentage of Ferro-manganese.	Sp. resistance (copper=1·00)	Temperature-coefficient, (20°-100°).		
			Alloy hard.	Alloy semi-annealed.	Alloy annealed.
100·00	0·00	1·00	·003202	------	------
99·58	0·42	1·07	·002579	------	------
99·26	0·74	1·19	·002167	------	------
91·88	8·12	11·28	·000138	------	·000184
91·03	8·97	11·74	·000120	------	------
88·97	11·03	14·07	·000065	------	------
86·98	13·02	20·40	·000016	—·000021	·000080
83·72	16·28	----	·000010	------	·000023
80·88	19·12	30·38	·000012	------	·000046
80·40	19·60	27·50	·000022	—·000032	·000066
77·80	22·20	----	------	------	·000053
77·20	22·80	35·90	—·000012	------	·000010
70·65	29·35	45·10	—·000024	------	·000021

It was found that specimens containing less than eighty per cent of copper could not be worked without frequent partial annealing. Two such specimens were tested, after rolling and again after subsequent annealing. They showed a negative coefficient after rolling, which may have been due to the previous heating, undergone in the process of working them into the necessary form; but since they were as nearly in the condition of the hard-rolled alloys as it was possible to make them, they have been classified in the table among the hard metals.

The coefficients of the hard-rolled alloys, including those above mentioned, have been used in the construction of the accompanying curve, (figure 1). Abscissæ are percentages of ferro-manganese present in the respective specimens; ordinates are the changes of resistance for 100° C. It will be seen that the coefficient of the unalloyed copper falls considerably below Matthiesen's standard, and that the addition of small quantities of ferro-manganese produces a further very rapid



decrease. With ten per cent of ferro-manganese, the change of resistance is less than one per cent for one hundred degrees. Alloys containing from fifteen to twenty per cent of ferro-manganese possess exceedingly small coefficients, the curve crossing the base line at the point corresponding to eighteen per cent. The curve is intended to represent the variations of alloys which are of the same temper, but it is not possible to determine in how far it does so. Indeed for the entire range from fifteen per cent to thirty per cent the coefficient may be given any value between +·00002 and −·00002, by varying

the temper of the metal. A positive coefficient could be obtained, however, in alloys containing more than twenty per cent of ferro-manganese, only by thoroughly annealing the specimen; whereas in metals containing a larger proportion of copper, either hardening or complete annealing developed a positive coefficient.

The marked influence of temper upon the conductivity of these alloys, renders it difficult to determine the precise law of the change in specific resistance with the composition. It appears, however, from the results presented in Table V, that the resistance increases nearly in direct proportion to the percentage of ferro-manganese.

Mr. Blood's investigation also included two alloys which contained nickel as well as ferro-manganese. The methods of preparation and measurement were identical with those which have already been described. The results, which are given in Table VI, show exceedingly small negative coefficients in the case of the hardened alloy. Annealing rendered the coefficient of the alloy containing the smaller percentage of nickel positive, and reduced the size of the coefficient of the other specimen.

TABLE VI.

Composition of the alloy.			Temperature coefficients.	
Copper.	Ferro-manganese.	Nickel.	Alloy (hard).	Alloy (annealed).
78·28%	14·07%	7·65%	−·000011	+·000007
52·51%	31·27%	16·22%	−·000039	−·000032

The experiments described in this paper, show that the alloys of ferro-manganese and copper, so far as their electrical behavior is concerned, must be considered as a distinct class. Up to the time of Mr. Weston's discovery of their properties, increase of conductivity with rise of temperature was supposed to be confined to electrolytes, and to the single solid conductor, carbon. Recent investigations have added sulphur to the list, and it is evident that this set of alloys, at least, belongs there also. It is not improbable that the further study of alloys containing metals of the iron group, will lead to the discovery of other combinations, possessing the same interesting and important characteristic.

ART. LVI.—*Fluid Volume and its Relation to Pressure and Temperature;*[1] by C. BARUS.

INTRODUCTORY.

1. THE present paper contains the introductory part of a series of experiments on the compressibility of liquids, now in progress at this laboratory. The incentive to the work was given by Mr. Clarence King. In its development I am benefited by his counsel.

The geological purposes in view make it necessary to obtain a preliminary survey of the whole field of inquiry. Experimental details will be filled in later.

2. The literature of the subject has recently been critically digested by Professor Tait.[2] Excellent excerpts are to be found in the Fortschritte der Physik. The work of Canton (1762–64), Perkin (1820–26), Œersted (1822), Colladon and Sturm (1827), Regnault (1847), Grassi (1851), Amaury and Descamps (1869), is discussed in most text-books. Since that date the contributions have been manifold, and are fast increasing. I shall therefore principally confine myself to such papers in which volume changes produced by the simultaneous influence of both pressure and temperature are considered.

Setting aside the literature[3] of critical points, which is too voluminous for admission here, the work of Cailletet[4] is first to be noted, as introducing a long range of pressures (700 atm.). Amagat's[5] early work contains a large temperature interval (0° to 100°), but applies for pressures below 9 atm., only. The results are discussed with reference to Dupré's[6] equation. Passing Buchanan's[7] and Van der Waals[8] results on the compressibility of water and solutions, I come to the important step in the subject made by Lévy[9], though he had been considerably anticipated by Dupré[10]. Lévy endeavors to prove that the internal pressure of a body kept at constant volume is proportional to its temperature. I have already stated[11] that Levy's position is antagonized by H. F. Weber,[12] Boltzmann,[13] Clausius[14]

[1] Communicated with the permission of the Director of the Geological Survey.
[2] Tait: Properties of matter.
[3] See Landolt and Bœrnstein's Physikalisch-chemische Tabellen, Berlin, J. Springer. 1883, p. 62.
[4] Cailletet: C. R., lxxv, p. 77, 1872.
[5] Amagat: C. R., lxxxv, pp. 27, 139, 1877; Ann. ch. et phys., xi, p. 520, 1877.
[6] Dupré: C. R., lix. p. 490, 1864; ibid., lxvii, p. 392, 1868.
[7] Buchanan: Nature, xvii, p. 439, 1878.
[8] Van der Waals: Beiblätter, i, p. 511, 1877.
[9] Lévy: C. R., lxxxvii, 1878, pp. 449, 488, 676, 554, 649, 826
[10] Dupré: Theorie mecan. de la chaleur, Paris, Gauthier-Villars, 1869, p. 51.
[11] Cf. this Journal. xxxviii, p. 407, 1889.
[12] H. F. Weber: C. R., lxxxvii, p. 517, 1878.
[13] Boltzmann: C. R., lxxxvii, pp. 593, 773, 1878.
[14] Clausius: C. R., lxxxvii, pp. 718, 1878.

and Massieu,[1] but that important experimental evidence is given in favor of the probable truth of the principle by Ramsay and Young. See below. Amagat's[2] work on the compression of gases must be mentioned because of its important bearing on pressure measurement. In two critical researches Mees[3] perfects Regnault's piezometer and re-determines the compressibility of water. Tait[4] and his pupils, Buchanan[5], Marshal, Smith and Omond,[6] and others carry the inquiry into compressibility and maximum density of water into much detail, and the data are theoretically discussed by Tait. Pressures as high as 600 atm. are applied. Solutions and alcohol are also tested for compressibility. Pagliani,[7] Palazzo and Vicentini,[8] using Regnault's piezometer, publish results for water and a number of other substances, mostly organic. They also examined mixtures. Temperature is varied between 0° and 100°. The results are discussed at length and show the insufficiency of Dupré's formula. DeHeen[9] who has spent much time in studying the volume changes of liquid, deduces a formula of his own chiefly in reference to the thermal changes of compressibility. Theory is tested by experiments. The researches which Amagat,[10] published at about this time are remarkable for the enormous interval of hydrostatic pressure (3000 atm.) applied. Ether and water are operated on. In later work these[11] researches are extended to include other liquid substances with the ulterior object of locating the lower critical temperature. The behavior of water is fully considered. Grimaldi[12] critically discusses the earlier work on the maximum density of water. He also examines the volume changes produced in a number of organic substances[13] by temperature (0° to 100°) and pressure (0 to 25 atm.), and finds Dupré's, DeHeen's and Konowalow's[14] formulæ insufficient.

[1] Massieu: C. R., lxxxvii, p. 731, 1878.

[2] Amagat: C. R., lxxxix, p. 437, 1879; ibid, xc, pp. 863, 995, 1880; ibid., xci, p. 428, 1880, and elsewhere.

[3] Mees: Beiblätter, iv, p. 512, 1880; viii, p. 435, 1884.

[4] Tait: Nature, xxiii, p. 595, 1881; Challenger Reports, ii, 1882, app., pp. 1 to 40; Proc. Roy. Soc. Ed., xi, p. 813, 1882–83; ibid., xii, 1883–84, pp. 45, 223, 226, 757; ibid., xiii, p. 2, 1884–85.

[5] Buchanan: Proc. Roy. Soc. Ed., x, 1880, p. 697.

[6] Marshal, Smith and Omond: Proc. Roy. Soc. Ed., xi, pp. 626, 809, 1882–83.

[7] Pagliani and Palazzo: Beibl., viii, p. 795, 1884; ix, pp. 149, 626, 809, 1885.

[8] Pagliani and Vicentini: Beibl, viii, p. 794, 1884; Journ. de phys., (2) xxx, p. 461, 1883.

[9] DeHeen: Bull. Soc. Roy. Belg., (3), ix, 1885, p. 550; Journal de phys., (2), viii, p. 197, 1889.

[10] Amagat: C. R., ciii, p. 429, 1886.

[11] Amagat: C. R., civ, p. 1159, 1887; ibid., cv, pp. 165, 1120, 1887.

[12] Grimaldi: Beiblätter, x, p. 338, 1886.

[13] Grimaldi: Beiblätter, xi, pp. 136, 137, 138, 1887; Ztschr. für phys. chem., ii, p. 374, 1888.

[14] Konowalow: Ztschr. für phys. chem., ii, p. 1, 1888.

At this stage of progress, the point of view gained in the extensive researches of Ramsay and Young[1] throws new light on the subject. They prove experimentally that if pressure p and temperature θ vary linearly ($p=b\theta-a$), the substance operated on does not change in volume. Ether, methyl and ethyl alcohol, acetic and carbonic dioxide are tested. Exceptional values for the case of acetic acid and nitrogen tetroxide are referred to dissociation. Utilizing James Thomson's[2] diagram, they point out that the locus of the isothermal minima and maxima intersect the locus of maximum vapor tensions at the critical point. Data are given for ether. Fitzgerald[3] reasoning from Ramsay and Young's results arrived at the theoretic results virtually given by Lévy (see above). Tait[4] who is still actively at work on high pressures has recently made further publication on the effect of dissolved substances on internal pressure. An endeavor to formulate Andrew's classical results is due to Dickson.[5] Fitzgerald[6] recently applied Clausius's[7] equation to a discussion of Ramsay and Young's data, and Sarrau[8] has similarly discussed Amagat's data.

3. A few references to thermal expansion of liquids, which enters incidentally into the present paper, must be added. Many formulæ have recently been devised and tested by Avenarius,[9] DeHeen,[10] Mendeleeff,[11] Thorpe and Rücker,[12] Jouk[13] and others,[14] not to mention older observers. None of these forms are satisfactory when long ranges of temperature are introduced, as was shown by Bartoli and Stracciati,[15] testing Mendeleeff's, and Thorpe and Rücker's formulæ, and by the discussion between Mendeleeff and Avenarius.

Special mention must be made of the celebrated papers of J. Willard Gibbs,[16] by whom the scope of graphic methods for exhibiting the thermo-dynamics of fluids was surprisingly

[1] Ramsay and Young: Phil. Mag., (5) xxiii, p. 435, 1887; ibid., xxiv, p. 196, 1887; Proc. Roy. Soc. Lond., xlii, p. 3, 1887.
[2] James Thomson: Phil. Mag., (5), xliii, p. 227, 1872; Nature, ix, p. 392, 1873.
[3] Fitzgerald: Proc. Roy. Soc., xlii, p. 50, 1887.
[4] Tait: Challenger Reports, Phys. and Chem., ii, (4), 1888; Proc. Roy. Soc. Ed., xv, p. 426, 1888.
[5] Dickson: Phil. Mag., x, p. 40, 1880.
[6] Fitzgerald: Proc. Roy. Soc. Lond., xlii, p. 216, 1887.
[7] Clausius: Wied. Ann., p. 337, 18 .
[8] Sarrau: C. R., xciv, pp. 639, 718, 845, 1882; ibid., ci, p. 941, 1885.
[9] Avenarius: Beibl., ii. p. 211, 1878; ibid., viii, p. 806, 1884.
[10] DeHeen: Bull. Ac. Roy. Belg., (3), iv, p. 526, 1882; Journ. Chem. Soc., xlv, p. 408, 1884.
[11] Mendeleeff: Chem. Ber., xvii, p. 139, 1884; Beibl., viii, p. 806, 1884.
[12] Thorpe and Rücker: Journ. Chem. Soc., xlv, p. 135, 1884.
[13] Jouk: Beibl., viii, p. 808, 1884.
[14] Rosenberg: Journ. d'Almeida, vii, p. 350, 1878.
[15] Bartoli and Stracciati: Beibl., ix, p. 510, 1885.
[16] J. Willard Gibbs: Trans. Conn. Acad., ii, (2), pp. 309, 382, 1873.

enlarged. The terms *isometric, isopiestic, isothermal, isentropics*, etc., are used in the present paper in the sense defined by Gibbs (l. c., p. 311).

4. Surveying the above researches as a whole, it appears at the outset that more work has been spent on the compressibility of water than the exceptional behavior of this substance justifies at the present stage of the inquiry. In other words the volume-pressure-temperature changes of the great majority of liquids probably conform closely with a general thermodynamic law, due respectively to Dupré and Lévy, and to Ramsay, Young and Fitzgerald. It is therefore first desirable to find the full importance of this law experimentally, and then to interpret the exceptional cases with reference to it. Again it appears that researches in which long pressure ranges are applied simultaneously with long temperature ranges, are urgently called for. It is from such work that further elucidation of this important subject is to be obtained.

Among pressure experiments the late researches of Amagat stand out by their originality and importance. One can not but admire the experimental prowess which has enabled him to penetrate legitimately into a region of pressures incomparably high, without lowering his standard of accuracy.

Apparatus.

5. *Force pump and appurtenances.*—In making the experiments detailed in the following pages I used a large Cailletet force pump, of the form constructed both by Ducretet of Paris, and by the Société Génevoise. Its efficiency is 1000 atm. It is made to be fed with water, but I found by using thin sperm oil, it was possible to facilitate the operations, because there is less danger of rusting the fine polished steel parts of the machine. The pump consists of two parts: the pump proper and the strong cylindrical trough into which the compression tubes are to be screwed. The trough is cannon-shaped, its axis vertical, and the open end uppermost. Pump and trough are connected by strong phosphor-bronze tubing, and similar tubes lead to the large Bourdon gauge by which the pressures are measured.

6. *Compression tubes and appurtenances.*—The substance to be tested is enclosed in capillary tubes of glass of very fine bore (·03^{cm} and less) and about ·6^{cm} thick, such as are used for thermometers. The length of these tubes *a b c*, figure 1, was about 50^{cm} or 60^{cm}. To insert them into the trough, the solid glass of the tube was swelled or bulged at *b* about 5^{cm} from one end, and then pushed through an axially perforated steel flange AA BB, in which they fitted snugly. The bulged end and the flange faced the inside of the trough, so as to be acted against by the pressure. To seal the tube *a b c*, in the steel flange AA BB fusible metal was poured around it at *f f*, and the joint was then further tightened by a thick coating of marine glue, *g g*. A strong hollow nut of iron surrounding both the lower end of the tube and the stem of the flange, fastened it to the trough by forcing it against a leather washer. When completely adjusted, the capillary tube projected about 40^{cm} or 50^{cm} clear above the trough. Pressure was transmitted through the oil of the pump to the mercury in the trough, which communicated directly with the open lower end of the capillary tube.

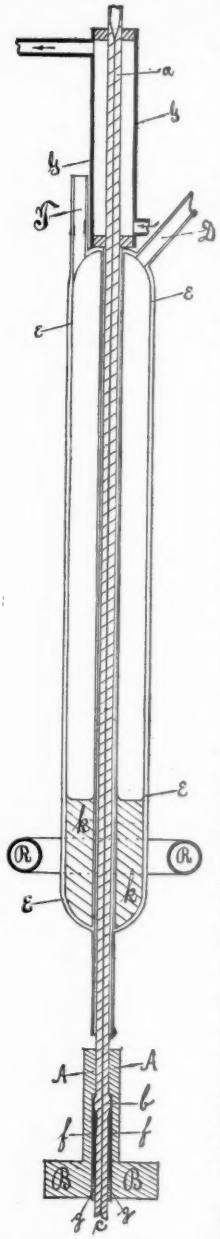


Fig. 1.—Capillary tube with appurtenances for measuring compressibility of fluids. Scale ½.

7. A thread of the (solid) substance to be acted on was introduced into the cleansed capillary, between two threads of mercury. This is a delicate operation, requiring much care; but the details of manipulation can not be given here. I will say merely that it is not advisable to seal the upper end, *a*, of the tube *a b c* by fusing the glass, because the strains introduced during cooling greatly diminish the strength of the tube. The end may be sealed by a thread of paraffine 5^{cm} long, properly inserted and kept solid by a cold water jacket, G G. Under these conditions the viscosity of paraffine is too great to admit of its being forced out of the glass by any pressure compatible with the strength of the tube. Faultless adhesion of the paraffine to the glass is however essential.

Passing from top to bottom of the charged capillary, *a b c*, one therefore encounters the following succession of threads: paraffine (5^{cm}), mercury (5^{cm}), substance (20^{cm}), mercury (25^{cm}) in communication with the mercury of the trough. Measure-

ments are made by observing the distance apart of the lower meniscus of the upper mercury thread, and the upper meniscus of the lower thread, with Grunow's cathetometer. When the adjustment is perfect the motion of the upper mercury thread is nearly zero.

8. To heat the sample to any required temperature, I surrounded the capillary tube *abc*, with one of my closed boiling tubes* of clear glass, *ee ee*. By connecting the latter with a condenser, the ebullition may be prolonged indefinitely. The whole length of thread of substance is thus virtually exposed in a vapor bath. Methyl alcohol (65°), water (100°), aniline (185°), and diphenylamine (310°) are available for boiling points. The liquid shown at *kk*, is heated by Wolcott Gibbs's ring burner *RR*. At high temperatures it is of course necessary to jacket the boiling tube appropriately with asbestos wicking (not shown), leaving only two small windows exposed, through which the ends of the thread may be seen with the telescope. When the tube has become fully heated, it is clear, and condensation takes place only in the condenser, connecting at *D*. By adjusting suitable white and black screens with reference to the line of sight, the image of the meniscus may be sharpened. Intermediate temperatures may be reached by boiling the substances under low pressures. For this purpose it is merely necessary to attach the open end of the condenser to Prof. R. H. Richards'† pneumatic exhausting pumps. Provision has been made at *T* for the introduction of a suitable thermometer, by which the temperature of the boiling tube may be checked.

To save space the description here given is a mere sketch. It is scarcely necessary to state that the manipulations are difficult throughout, and that with the best of care breakage of tubes and other failures of experiment are a frequently recurring annoyance. Special pains must be taken to select well annealed glass; otherwise the internal stress adds itself to the applied stress, and the tube is easily broken. Hot vapor baths must not be removed until the tube *a b c* is thoroughly cold. The capillary does not outlast many series of experiments: for sheared glass undergoes a gradual molecular change very analogous to permanent set. Eventually the tube may be ruptured at less than $\frac{1}{3}$ the original test pressure.

9. *Pressure measurement.*—It is easily seen that the method of experiment is necessarily such that temperature is kept constant, while pressure is varied at pleasure.

* Bulletin U. S. G. S., No. 54, pp. 86 to 90, 1889.
† Richards: Trans. Am. Inst. Mining Eng., vi, p. 1, 1879.

To measure pressure, I used a Bourdon gauge,* graduated in steps of 10 atm. each as far as 1000 atm. So graduated the gauge registered smaller differences of pressure than could be measured in terms of the volume changes of the liquid in the capillary tubes.

To test the gauge I compared it with a similar gauge graduated as far as 300 atm., and found the difference no larger than the error of reading. Again I compared the guage indications with the changes of the electrical resistance of mercury under identical conditions of pressure, and found the results equally satisfactory, as will be explained elsewhere.

Curious results were obtained on comparing the gauge with a closed air manometer. The results calculated with reference to Boyle's law, i. e. for isothermal expansion, were found wholly discrepant. The difficulty was interpreted by computing with reference to Poisson's law. Some data are given in table 1, where p, v, k, denote pressure, volume and the specific heat ratio, respectively. The error at $p = 100$ is due to time lost in making the measurement, since it is here that the volume changes are large and require specially adjusted telescopes for close reading.

TABLE 1.—Compressibility of air. Test of Gauge.

p	v	lg $v^k p$		p	v	lg $v^k p$
atm.				*atm.*		
100	1030	6·25		100	1040	6·25
200	550	6·16		200	552	6·17
300	400	6·15		300	393	6·14
400	329	6·15		400	324	6·16
500	----	----		500	285	6·16

Quick manipulation presupposed, this method is probably available for the measurement of k, particularly with reference to its pressure variation. It follows also that when work is done in capillary tubes, much time must be allowed before the observed volume changes can be considered isothermal.

Since the gauge is based on Hooke's law, errors of the zero point are eliminated by working between indicated pressure and taking differences of reading. So far as the relative pressures are concerned, it is then merely necessary that the attached dial and mechanism be virtually a scale of equal parts.

* I think Mr. Tait who has constructed other gauges based on Hooke's law, under-estimates the ingenuity of Bourdon's gauge. By increasing the number of coils, or by suitably adjusting a mirror index, the gauge can be made serviceable without a multiplying gear. Read off directly the only limit to the scientific efficiency of such a gauge is the viscosity of the Bourdon tube. My own experiments on improving this gauge have thus far been failures, chiefly however because of insufficient facilities for working with steel tube.

Finally I compared the Bourdon gauge with a form of Tait gauge of my own, in which the volume expansion of a suitable steel tube due to pressure, is measured externally. Leaving further description to be given elsewhere, I will here insert an example of the results obtained, selected at random.

TABLE 2.

Comparison of gauges.

	Bourdon.	N. G.		Bourdon.	N. G.		Bourdon.	N. G.
	atm.	cm.		atm.	cm.		atm.	cm.
$p=$	0	0	$p=$	500	870	$p=$	1000	1700
	100	160		600	1045			
	200	335		700	1210			
	300	520		800	1370			
	400	690		900	1530			

Here the reading of the new gauge is given under N. G. Constructing the data graphically, and remembering, that the deviations are to be apportioned between the gauges, it appears that the error must everywhere be less than 10 atm., under most unfavorable conditions.

No stress was placed on the absolute correctness of the standard atmosphere employed. The results sought follow equally well for an approximate standard, correctly multiplied.

11. *Volume changes of glass tubes.*—Professor Tait* has given the following expression for the volume increment of a cylinder subjected to internal pressure:

$$\frac{\Pi a_0^2}{a_1^2 - a_0^2}\left(\frac{1}{k} + \frac{a_1^2}{a_0^2}\frac{1}{n}\right),$$

where Π is the pressure, $1/k$ and n the compressibility and the rigidity of the glass, and where a_0 and a_1 denote the inner and the outer radius of the tube, respectively. In my case $a_0 = \cdot 015^{cm}$ or less, $a_1 = \cdot 3^{cm}$. It is therefore permissible to neglect the factor in the above expression which involve compressibility, with an error no greater than a few tenths per cent. Hence if the proper value† of n be introduced, and P be measured in atmospheres, the above expression reduces approximately‡ to $4\Pi 10^{-6}$. Unfortunately this correction is by no means negligible, and may in unfavorable cases amount to as much as 5 per cent of the corresponding volume decrement of the liquid to be tested. The case is worse: most of the experiments are to be made between 60° and 300°, for which large interval the rigidity of glass can not be said to be known.

* Tait: Challenger Reports, 1882, appendix, p. 29.

† Everett: Units and phys. constants, Macmillan, 1879, p. 53.

‡ The correction is less than the above result, since only the right sectional expansion affects the measurement.

Hence, instead of introducing arbitrary considerations I resolved to neglect the correction altogether, in favor of direct test experiments made with mercury and water. The compressibility of mercury is two small to be measurable by the present method. Hence, since its compressibility is known, it is well adapted for testing the errors of the apparatus.

In table 3 I have given the temperature, θ, and the length, L, of the mercury thread observed; also the volume decrement v/V per unit of volume, for each pressure p, as well as the corresponding mean compressibility β. Many methods were tried, but the best results were obtained with a thread of mercury enclosed between end threads of paraffine. At the low temperature, 30°, the lower thread was alcohol. At high temperatures the greatest care must be taken to free the thread from adhering air bubbles, or of globules of volatile liquid, for in expanding they utterly vitiate the results, as I found in more than one instance.

TABLE 3.

Compression of mercury to test tubes.

θ, L	p	$\frac{v}{V}\times 10^3$	$\beta\times 10^6$	θ, L	p	$\frac{v}{V}\times 10^3$	$\beta\times 10^6$
30°	20	·0	--	185°	20	·0	--
16·7cm	100	·2	2	17·1cm	100	1·1	14
	200	·3	2		200	2·2	13
	300	·7	3		300	2·6	9
	400	1·5	4		400	4·2	11
	mean	---	3		mean	---	12
65°	20	·0	--		Another	thread	
16·8cm	100	·6	8	185°	20	·0	--
	200	2·0	14	19·3cm	100	·8	10
	300	2·0	8		200	3·0	17
	400	3·0	8		300	3·8	14
	mean	---	9		400	4·7	13
100°	20	·0	--		mean	---	13
16·9cm	100	·7	10	310°	20	·0	--
	200	1·5	9	19·7cm	100	1·2	15
	300	2·5	8		200	2·6	14
	400	2·1	8		300	4·0	15
	mean	---	9		400	5·3	14
					mean	---	15

This table is reassuring. From the known low temperature compressibility of mercury,* it appears that the error of β made by neglecting Tait's correction is of the order of 10^{-6}, and that it is not greater than the unavoidable errors of measurement. Again since the compressibility of the organic substances examined as in all cases much greater than 60×10^{-6},

* Everett: l. c, pp. 52. 53. Cf. Amagat: C. R. cviii, p. 228, 1889; Journ. de phys., (2), viii, p. 197, 1889; Tait: l. c.

the said error of β is never larger than 2 per cent. By comparing table 3 with tables 4 to 18, (ϑ), it will be seen that the results at high temperatures are much more favorable. Similar inferences were obtained with water, which may therefore be omitted here.

13. *Isothermals and isentropics.*—To obtain the isothermals of the compressed liquids rigorously, it is necessary to wait a long time after each compression. By so doing the tube is seriously weakened, and at high temperatures, in virtue of the diminished viscosity (cf. § 8), it is probably even distorted. It appears, however, that for liquids like the present, the distinction between isothermal and adiabatic compression is beyond the scope or sensitiveness of the present method of volume measurement. Hence, I made my observations by varying pressure from 20 atm. to the maximum, and then from the maximum back to 20 atm., with only such allowance of time as was necessary to take the observations at the successive stages of pressure. Near the critical temperature this mode of procedure is no longer warranted.

Throughout the work the chief reliance was placed on the constancy of the fiducial zero. The volume decrements corresponding to a given pressure must be identical, no matter whether they are observed in the pressure increasing or pressure decreasing march of the measurements.

14. *Thermal expansion.*—Measurements of heat expansion are necessary for the coördination of the results. Without a thermometer tube, such measurements are not very accurate; and the inaccuracy is much increased by an unavoidable breaking off of the ends of the mercury thread, whenever the substance operated on solidifies. In passing from one constant temperature to another, an exchange of boiling tubes is necessary. It is difficult to keep the substance fused during the whole time of readjustment. On solidification the charge contracts as much as 10 per cent. The mercury thread is therefore forced into the vacuities in the axis of the solid thread. After fusing again it will often be found that the mercury thread is broken into distinct pieces, sometimes in great number, alternating with small threads of substance. All of these must be measured, an operation which is not only excessively tedious, but makes the expansion measurement, inaccurate. For this reason I added no correction for the expansion of glass. The errors thus introduced may amount to 2 or 3 per cent in unfavorable cases. See tables 5 to 19. At high temperature such corrections would be arbitrary for the reasons given in § 11. Here however, it is probably quite negligible, because of the large volume expansions.

Experimental Results.

15. The bulk of the present experiments were made as detailed in § 6, earlier data being rejected. Throughout the tables L is the length of the thread of substance, at the temperature θ; v/V is the corresponding volume-decrement due to the burden of p atmospheres. Finally, β is the mean compressibility between the initial pressure p_0 and the pressure given. Values marked, observed and calculated will be discussed below § 30.

16. *Ether.*—The results for ether are given in table 4. Manipulations were made very difficult, because of traces of sulphur retained by the liquid. This destroys the cohesion of the mercury thread, probably by reducing its surface tension. Above 100° the thermal expansion increases enormously, so that I found it necessary to operate with two threads, a long one for low temperatures, and a short one for 310°. Since the initial pressure could not be kept at 20 atm., the tubes not being long enough, I reduced all data to the uniform pressure $p_0=100$ atm. Table 5 shows the corresponding expansion data. It may be noted that supposing the given conditions to hold linearly, ether would cease to expand at 1100 atm. Cf. § 38.

Table 4.

Compressibility of Ether, referred to 100 Atm.

θ, L	p	Observed $\frac{v}{V}\times 10^3$	$\beta\times 10^6$	Comput'd $\frac{v}{V}\times 10^3$	Diff. $\times 10^3$	$\vartheta\times 10^6$	$\vartheta_0\times 10^6$
29°	100	0·0	----	0·0	----		
	200	15·6	156	15·4	+·2	165	194
14·37cm	300	28·9	145	28·9	·0		
	400	40·8	136	40 9	−·1		
65°	100	0·0	----	0·0	----		
	200	20·7	207	20·5	+·2	226	282
15·18cm	300	37·7	189	37·8	−·1		
	400	52·8	176	52·8	±·0		
100°	100	0·0	----	0·0	----		
	200	30·5	305	29·9	+·6	343	497
16·25cm	300	53·6	268	53·4	+·2		
	400	72·2	241	72·8	−·6		
185°	100	0·0	----	0·0	----		
20·08cm	200	74·1	741	71·5	+2·6	1005	10060
	300	115·5	577	114·7	+ ·8		
	400	143·5	478	145·6	−2·1		
310°	100	0	----	0·0	----		
*14·59cm	200	382	3820	383	−1	34250	
	300	462	2310	460	+2		
	400	502	2510	503	−1		

* Second sample.

TABLE 5.

Thermal expansion of Ether, $\frac{v}{V} \times 10^3$, referred to 29°.

Atm. =		100	200	300	400
θ=	29°	0	0	0	0
	65	57	51	48	43
	100	131	114	103	93
	185	397	315	274	246
	310	1770	733	528	435

17. *Alcohol.*—The alcohol used was the commercial absolute spirit. Table 6 contains the observations for compressibility. All observations are referred to 150 atm., for the tube was not long enough for observations corresponding to lower initial pressures. Thermal expansions are given in table 7.

TABLE 6.

Compressibility of Alcohol, referred to 150 Atm.

θ, L	p	Observed $v/V \times 10^3$	$\beta \times 10^6$	Comput'd $v/V \times 10^3$	Diff. $\times 10^3$	$\vartheta \times 10^6$	$\vartheta_0 \times 10^6$
28°	150	0·0	----	0·0	·0		
	200	4·3	86	4·3	·0	89	101
9·45cm	300	12·7	85	12·6	+·1		
	400	20·2	81	20·2	·0		
65°	150	0·0	----	0·0	·0		
	200	5·5	110	5·6	−·1	115	136
9·78cm	300	16·4	109	16·0	+·4		
	400	25·1	100	25·5	−·4		
100°	150	0·0	----	0·0	·0		
	200	8·4	168	7·6	+·8	158	201
10·27cm	300	21·6	144	21·5	+·1		
	400	33·1	132	34·0	−·9		
185°	150	0·0	----	0·0	·0		
	200	16·0	320	15·4	+·6	331	598
11·62cm	300	41·1	274	40·9	+·2		
	400	61·2	245	61·8	−·6		
310°	150	0	----				
	200	211	4200	219	−8	13830	
21·75cm	300	335	2220	330	+5		
	400	384	1530	385	−1		

TABLE 7.

Thermal expansion of Alcohol, $\frac{v}{V} \times 10^3$, referred to 28°.

Atm. =		150	200	300	400
θ=	28°	0	0	0	0
	65	35	35	31	30
	100	87	82	78	73
	185	229	217	195	178
	310	1290	826	555	447

18. *Palmitic acid.*—Data for palmitic acid are given in tables 8 and 9 on a plan uniform with the above. Owing to accidents two threads were observed; the first between 65° and 185°, and the second between 65° and 310°. At 65°, solidification set in at about 400 atm. The result is a distortion of the curvature of the isothermal. Difficulties were encountered from breaks of the mercury thread. In this and the following tables, two values of v/V are usually inserted. They were obtained during the pressure increasing and the pressure decreasing march of the measurements.

TABLE 8.

Compressibility of Palmitic acid, $C_{16}H_{32}O_2$, referred to 20 atm.
Melting point 62°; Boiling point 350°.

L, θ	p	Observed. $\frac{v}{V}\times 10^3$	Observed. $\frac{v}{V}\times 10^3$	$\beta\times 10^6$	Comput'd $\frac{v}{V}\times 10^3$	Diff. $\times 10^3$	$\vartheta\times 10^6$	$\vartheta_0\times 10^6$
65°	20	0·0	0·0	---	†0·0	·0	91	93
16·72cm	100	7·2	7·2	90	7·1	−·1		
	200	15·0	15·3	85	15·3	−·1		
	300	22·8	23·1	82	23 0	−·1		
	*400	31·1	31·1	82	30·1	+·2		
100°	20	0·0	0·0	---	0·0	·0	102	104
17·16cm	100	8·1	8·1	101	7·8	+·3		
	200	16·9	16·3	93	16·9	−·3		
	300	25·5	25·5	91	25·4	+·1		
	400	33·3	33·3	88	33·2	+·1		
185°	20	0·0	0·0	---	0·0	·0	160	165
18·50cm	100	12·1	12·1	151	12·1	·0		
	200	26·3	26·3	146	25·5	−·2		
	300	37·2	37·8	134	37·5	·0		
	400	48·2	47·7	127	48·5	−·4		
Second sample.								
65°	20	0·0	0·0	---				
14·63cm	100	6·5	6·9	84				
	200	15·1	15·1	84				
	300	22·9	22·3	81				
	400	29·5	29·5	78				
310°	20	0·0	0·0	---	0·0	·0	330	351
17·54cm	100	23·4	24·6	300	23·7	+·3		
	200	47·4	48·3	265	47·5	+·4		
	300	66·3	67·9	240	67·2	−·1		
	400	82·6	84·3	220	83·8	−·1		

TABLE 9.

Thermal expansion of Palmitic acid, $\frac{v}{V}\times 10^3$, referred to 65°.

Atm.=		20	100	200	300	400
θ=	65°	0	0	0	0	0
	100	26	25	24	23	24
	185	107	101	93	91	87
	310	199	179	159	145	133

* Solidifying. † Including the lower series.

19. *Toluidine para.*—Tables 10 and 11 contain data for para toluidine. A feature of these results is the circumflexure of the isopiestics in the undercooled part of their course. This is probably not an error, since it recurs under similar conditions in case of thymol, § 23. If contraction due to cooling were to continue at the rate shown in table 12, there would be no volume change at 1400 atm. To solidify the undercooled liquid, as much as 500 atm. were necessary.

TABLE 10.

Compressibility of Para-Toluidine, $C_7H_7NH_2$, referred to 20 atm.

Boiling point, 198°; melting point, 43°.

θ, L	p	Observed. $\frac{v}{V}\times 10^3$	Observed. $\frac{v}{V}\times 10^3$	$\beta\times 10^6$	Computed $\frac{v}{V}\times 10^3$	Diff. $\times 10^3$	$\vartheta\times 10^6$	$\vartheta_0\times 10^6$
*28°	20	0·0	0·0	---	0·0	±·0	--	
14·14cm	100	4·3	4·6	56	4·6	−·1	59	60
	200	10·0	10·0	56	10·2	−·2		
	300	15·8	15·6	56	15·5	+·2		
	400	20·6	20·9	55	20·5	+·2		
65°	20	0·0	0·0	---	0·0	±·0	--	
14·73cm	100	5·5	5·5	69	5·3	+·2	68	69
	200	11·6	11·9	65	11·7	±·0		
	300	17·4	17·4	62	17·7	−·3		
	400	23·5	23·5	62	23·4	+·1		
100°	20	0·0	0·0	---	0·0	·0	87	88
15·02cm	100	6·3	6·3	79	6·8	−·5		
	200	14·5	14·5	81	14·7	−·2		
	300	22·2	22·3	79	21·1	+·1		
	400	29·0	29·3	77	28·8	+·4		
185°	20	0·0	0·0	---	0·0	·0		
16·36cm	100	11·0	10·9	137	10·6	+·4	138	142
	200	22·8	22·8	127	22·5	+·3		
	300	33·4	33·4	119	33·1	+·3		
	400	42·4	42·2	112	43·1	−·8		
310°	20	0·0	0·0	---	---	0·	392	422
19·05cm	100	29·0	29·4	365	276	+2·		
	200	56·1	? 52·0	300	545	+2·		
	300	76·2	75·7	271	763	−0·		
	400	92·7	92·5	243	945	−2·		

TABLE 11.

Thermal expansion of Para-Toluidine, $\frac{v}{V}\times 10^3$, referred to 28°.

Atm.=		20	100	200	300	400
θ=	28°	0	0	0	0	0
	65	42	41	40	39	38
	100	63	60	57	56	53
	185	158	149	142	136	131
	310	348	313	287	265	247

* Liquid under-cooled. Solidifies at 500 atm.

20. *Diphenylamine.*—Values for diphenylamine are given in tables 12 and 13. The initial pressure is unfortunately zero. This introduces a possible discrepancy, since the zero of the gauge is not vouched for.

TABLE 12.

Compressibility of Diphenylamine, $NH(C_6H_5)_2$, referred to zero atm.

Melting point, 54°; boiling point, 310°.

L, θ	p	Observed. $\frac{v}{V}\times 10^3$	Observed. $\frac{v}{V}\times 10^3$	$\beta\times 10^6$	Computed $v/V\times 10^3$	Diff. $\times 10^3$	$\vartheta\times 10^6$	$\vartheta_0\times 10^6$
16·2cm 65°	0	0·0	0·0	---	0·0	− ·0		
	100	6·5	6·0	63	6·3	− ·0	65	65
	200	11·9	11·9	60	12·2	− ·2		
	300	17·9	17·3	59	17·9	− ·3		
	400	23·2	22·5	57	23·5	− ·7		
	500	29·2	28·4	57	28·4	+ ·9		
16·4cm 100°	0	0·0	0·0	---	0·0	·0		
	100	6·1	6·3	62	6·7	− ·5	69	69
	200	12·8	13·1	64	13·1	− ·2		
	300	19·3	19·3	64	19·0	+ ·3		
	400	24·6	25·1	62	24·7	+ ·1		
	500	29·9	30·5	60	30·1	+ ·1		
17·7cm 185°	0	0·0	0·0	---	0·0	+ ·0	110	110
	100	11·2	10·7	110	10·4	+ ·6		
	200	20·6	20·3	102	20·0	+ ·5		
	300	29·2	28·9	97	28·9	− ·1		
	400	37·1	36·1	91	37·0	− ·4		
	500	44·1	44·3	89	44·7	− ·5		
19·7cm (20·3cm) 310°	0	0·0	0·0	---	·0	·0		
	100	18·5	17·8	202	19·0	−1·2	213	213
	200	36·1	36·1	190	36·0	+ ·1		
	300	51·5	50·7	176	50·3	+ ·7		
	400	62·4	63·5	161	63·1	− ·1		
	500	74·1	71·1	152	74·6	·0		

TABLE 13.

Thermal expansion of Diphenylamine, $\frac{v}{V}\times 10^3$, referred to 65°.

Atm.=		0	100	200	300	400	500
θ=	65°	0·0	0·0	0·0	0·0	0·0	0·0
	100	12·4	12·4	11·3	10·1	10·1	11·0
	185	93·0	88·0	83·1	80·0	78·0	76·0
	310	235·	221·	205·	193·	186·	178·

21. *Caprinic acid.*—Tables 14 and 15 finally give the results for caprinic acid. Thermal expansion is irregular, possibly due to motion of the thread in the tube, so that virtually two threads were observed. The substance has a low melting point, 30°, and is easily under-cooled to 25°. It then solidifies under 300 atm.

TABLE 14.

Compressibility of Caprinic acid, $C_{10}H_{20}O_2$, referred to 20 atm.

Melting point, 30°; boiling point, 269°.

θ, L	p	Observed. $v/V \times 10^3$	Observed. $v/V \times 10^3$	$\beta \times 10^6$	Computed $v/V \times 10^3$	Diff. $\times 10^3$	$\vartheta \times 10^6$	$\vartheta_0 \times 10^6$
30°	20	0·0	0·0	---	0·0	·0		
	100	4·9	5·7	66	5·9	−·6	76	76
under-cooled	200	13·4	12·9	73	12·9	+·3		
15·91^{cm}	300	19·5	19·8	71	19·5	+·2		
	400	25·5	25·8	68	25·7	·0		
65°	20	0·0	0·0	---	0·0	·0		
14·39^{cm}	100	7·3	7·0	90	7·3	−·1	95	97
	200	16·1	15·9	89	16·0	·0		
	300	23·6	23·9	84	23·8	·0		
	400	31·4	31·1	82	31·3	·0		
100°	20	0·0	0·0	---	0·0	·0	119	121
16·85^{cm}	100	8·5	9·1	110	9·0	−·2		
	200	19·1	20·1	109	19·5	+·1		
	300	29·1	28·7	104	29·1	−·1		
	400	36·8	36·8	97	37·8	+·2		
185°	20	0·0	0·0	---	0·0	·0	200	207
18·30^{cm}	100	15·3	15·1	190	14·9	+·3		
	200	31·2	31·1	173	31·2	·0		
	300	45·4	45·5	163	45·2	+·3		
	400	57·4	57·1	151	57·7	−·4		

TABLE 15.

Thermal expansion of Caprinic acid, $\frac{v}{V} \times 10^3$, referred to 30°.

Atm.=		20	100	200	300	400
θ=	30°	0	0	0	0	0
	65	30	28	28	26	25
	100	59	55	52	49	47
	185	151	139	129	120	113

22. *Paraffine.*—Results for paraffine are in hand in large number. The best of these are given in tables 16 and 17. At 64°, solidification set in at 400 atm., changing the curvature of the isothermal. Supposing the present conditions to hold indefinitely, there would be no contraction on cooling under 1200 atm.

23. *Thymol.*—Finally tables 18 and 19 contain data for thymol. Like toluidine, § 19, thymol admits of considerable undercooling; and the isopiestics show circumflexure in that region. Supposing all conditions to hold, no volume changes would ensue on cooling under 1200 atm.

TABLE 16.

Compressibility of Paraffine referred to 20 atm. Melting point 55°.

L, θ	p	Observed: $\frac{v}{V}\times 10^3$	Observed: $\frac{v}{V}\times 10^3$	$\beta\times 10^6$	Comput'd $\frac{v}{V}\times 10^3$	Diff. $\times 10^3$	$\vartheta\times 10^6$	$\vartheta_0\times 10^6$
64°	20	0·0	0·0	----	0·0	—·0	88	89
15·86cm	100	6·8	6·5	83	6·8	—·1		
	200	14·9	14·9	83	14·8	+·1		
	300	23·6	23·8	84	----	----		
	400	solidify'g	(56·6)	(149)	----	----		
100°	20	0·0	0·0	----	0·0	—·0		
16·28cm	100	8·5	8·5	106	8·5	·0	111	114
	200	18·5	18·7	103	18·5	+·1		
	300	27.6	27·7	99	27·4	+·2		
	400	35.6	35·8	94	35·8	—·1		
185°	20	0·0	0·0	----	0·0	·0		
17·57cm	100	13·8	13·8	172	13·3	+·5	178	184
	200	27·9	28·2	156	28·1	·0		
	300	41·2	41·4	147	41·1	+·2		
	400	52·3	52·0	137	52·7	—·5		
310°	20	0·0	0·0	----	0·0	·0		
19·70cm	100	26·8	26·2	331	26·0	+·5	366	392
	200	51·9	52·1	289	51·7	+·3		
	300	72·4	71·8	257	72·7	—·6		
	400	89·9	89·6	236	90·3	—·6		

TABLE 17.

Thermal expansion of paraffine, $\frac{v}{V}\times 10^3$ referred to 64°.

Atm.=		20	100	200	300	400
θ=	64°	0·0	0·0	0·0	0·0	0·0
	100	26·4	24·1	23·1	22·6	22·1
	185	108·0	100·0	92·9	87·8	83·8
	310	241·0	210·0	196·5	181·0	167·0

24. Similar data are in hand for benzoic acid, monobrom camphor, α-naphtol, azo-benzol, vanilline, naphthaline, and monochloracetic acid But as the data are less complete and add no new features to the discussion, I omit them here.

To illustrate the general character of the results I have constructed the data for para-toluidine graphically in figures 2 and 3. The former shows the relative isothermal volume decrements the latter the relative isopiestic volume increments. The undercooled region is marked by a.

TABLE 18.

Compressibility of Thymol, $C_{10}H_{14}O$, referred to 20 atm. Melting point 53°, boiling point 233°.

L, θ	p	Observed. $\frac{v}{V}\times 10^3$	Observed. $\frac{v}{V}\times 10^3$	$\beta\times 10^6$	Comput'd $\frac{v}{V}\times 10^3$	Diff. $\times 10^3$	$\vartheta\times 10^6$	$\vartheta_0\times 10^6$
*28°	20	0·0	0·0	----	0·0	----	--	
14·67cm	100	5·5	5·3	67	5·1	+·3	65	66
	200	10·9	11·0	61	11·1	−·1		
	300	17·0	17·0	61	16·7	+·3		
	400	21·8	21.7	57	22·1	−·4		
64°	20	0·0	0·0	----	0·0	----	--	
15·29cm	100	5·6	5·4	69	5·7	−·2	74	75
	200	12·4	12·3	69	12·6	−·2		
	300	19·6	19·9	70	19·0	+·7		
	400	25·5	24·5	66	25·1	−·1		
100°	20	0·0	0·0	----	0·0	----	--	
15·78cm	100	7·6	7·5	94	7·4	+·1	96	97
	200	16·2	16·2	90	16·0	+·2		
	300	24·4	24·2	86	23·9	+·4		
	400	30·7	30·9	80	31·4	−·6		
185°	20	0·0	0·0	----	0·0	----	--	
17·05cm	100	12·3	12·2	153	12·2	·0	161	166
	200	26·1	25·9	144	25·8	+·2		
	300	38·0	37·8	135	37·8	+·1		
	400	48·3	48·5	127	48·8	−·4		
310°	20	0	0	----	†0	----		
19·5cm	100	3·3	3·2	407	3·1	+·2	448	487
	200	61·1	60·5	338	6·1	+·1		
	300	83·6	83·6	299	8·4	−·1		
	400	102·0	101·0	267	10·3	−·2		
310°								
16·47cm	20	0		----				
	100	3·4		425				
	200	62·4		347				
	300	82·5		295				
	400	102·0		269				

TABLE 19.

Thermal expansion of Thymol, $\frac{v}{V}\times 10^3$, referred to 28°.

Atm.=		20	100	200	300	400
θ=	28°	0	0	0	0	0
	65	42	43	41	39	39
	100	76	73	71	68	65
	185	162	154	145	138	130
	310	329	293	263	239	220

* Liquid undercooled. † From both the 310° series.

METHOD OF DISCUSSION.

25. *Isothermal band.*—Having given certain corresponding values of pressure and volume obtained at any given temperature, let a close-fitting function be investigated, such that for the same pressures, the calculated values of volume decrement must eventually be greater than the observed decrements will be. Let another function be investigated, such that for the same pressures, the calculated values of volume decrement must eventually be less than the observed values will be. From the nature of the variation, the observed or actual relation between volume and pressure will probably lie within the band or pathway included between the two limiting functions in question.

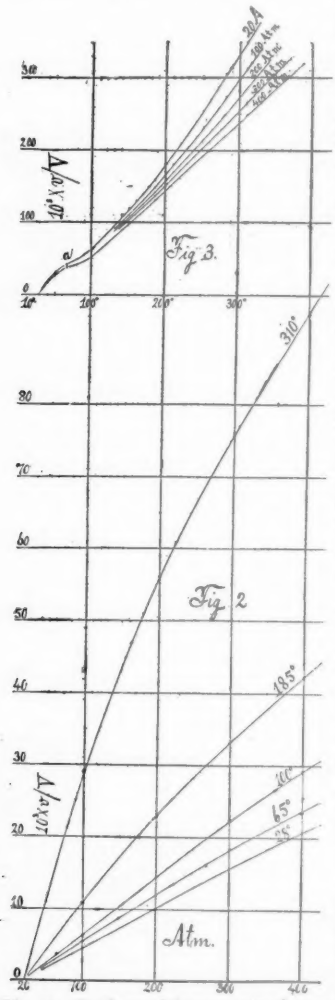


Fig. 2.—Isothermal decrements of paratoluidine, referred to unit of volume at 20 atm. and the respective isothermal temperatures.

Fig. 3.—Isopiestic increments of paratoluidine, under the same conditions. *a*, region of undercooling.

Suppose it is possible (the proof must be given by trial) to so adjust the two functions, that throughout the interval of observation they both fall within the limits of error. Then any property which is simultaneously predicted by both functions, may confidently be assumed as the property of the unknown isothermal. So long as the functions do not diverge seriously, there is here given a judicious mode of extrapolation, by which relations beyond the limits of experiment may be apprehended.

26. *Quadratic constants.*—In order to arrive at the probable nature of such functions, I passed parabolas through the observations. The ordinary vertical parabola is clearly inapplicable. It predicts a maximum and is therefore not compatible with the locus to be found. Nevertheless the zero-compressibility may thus be deduced, and from the relation of the two constants

inferences as to curvature may be obtained. In table 20 I have entered the two constants in question, supposing that $y_\theta = 10^3 \times v/V = mp - np^2$, where y_θ is a thousand times the volume decrement at pressure p, under conditions of constant temperature θ.

TABLE 20.
Quadratic constants.

Substance.	θ	$10^3 \times m$	$10^6 \times n$	Substance.	θ	$10^3 \times m$	$10^6 \times n$
Ether	310°	---	---	Diphenylamine	310°	197	92
	185	776	990		185	113	54
	100	340	346		100	64	3
	65	224	170		65	62	12
	29	167	107	Caprinic Acid	185	196	125
Alcohol	310	---	---		100	116	46
	185	---	---		65	92	27
	100	178	209		30	71	5
	65	111	28	Paraffine	310	349	320
	28	87	20		185	177	110
Palmitic Acid	310	315	267		100	110	43
	185	161	93		65	83	9
	100	100	36	Thymol	310	435	484
	65	88	25		185	159	85
Para-Toluidine	310	387	404		100	97	40
	185	141	81		65	69	2
	100	81	6		28	67	26
	65	69	25				
	28	56	3				

COMPRESSIBILITY INCREASING INVERSELY AS THE FIRST POWER OF THE PRESSURE BINOMIAL.

27. *Transition to exponential constants.*—These data show that compressibility increases at a rapidly accelerated rate with temperature, and that compressibility m and the datum for curvature n, are intimately related. This suggests the probability of a fundamental relation between y_θ and p, independent of the material operated on. § 38. In case of alcohol and ether at 310°, quadratic constants are manifestly impossible; for the maximum would lie within the field of observation. This is to some extent true for ether at 185°. Rejecting these exceptional cases, and considering the relation of m and n separately for each substance and collectively for all, it appears that a relation $2n = b(m - a)$ is available for trial. Since $y = mp - np^2$, or $dy/dp = m(1 - 2np/m)$, replace m by ϑ and $2n/m$ by a, for the sake of distinction. Then inasmuch as the quadratic equation applies more accurately in proportion as p is small, it may be nearly replaced by $dy/dp = \vartheta/(1 + ap)$, whence

$$y = l n (1 + ap)^{\vartheta/a} \quad . \quad . \quad . \quad . \quad (2)$$

This equation has an advantage over the other, since it does

not predict a maximum. It is therefore more in keeping with the isothermals of the above pages. In view of its simplicity, and of the additional fact that for $p=\infty$, $y=\infty$ generally, it may be taken as one limit of the isothermal band described in § 25.

$(A+p)$, where A is constant, is conveniently termed the *pressure binomial*. Approximate values of the constants in (2) might be derived from table 20, since $a=b(m-a)/m$, and $\vartheta/a=m^2/b(m-a)$, nearly. I was inclined to infer that at the melting point, for the above class of substances, compressibility is constant and independent of pressure. In such a case $\vartheta=a$ would be the criterion of fusion. Subsequent results did not substantiate this surmise. Another similar inference that the resistance to compression is equal to the incipient resistance to extension even in liquids, and that therefore $1/\vartheta$ must have a constant value at the boiling point independent of substance is not warranted by the experiments made.

28. *Properties of the exponential.*—Certain salient properties of equation (2) may be grouped together here. The occurrence of $y=10^3v/V=\infty$ for $p=\infty$ is not a fatal objection against the equation. For its application necessarily ceases at a finite value of p, i. e. at the point of solidification of the substance, by pressure. As far as this point equation (2) may faithfully represent the volume decrements observed. Suppose for a given substance $y'=ln(1+a_0(p+p_0)^{\vartheta_0/a_0}$ and simultaneously $y_0=ln(1+a_0p_0)^{\vartheta_0/a_0}$, where p and p_0 are any two consecutive intervals of pressure. Then

$$y=y'-y_0=ln\left(1+\frac{a_0}{1+a_0p_0}p\right)^{\vartheta_0/a_0} \quad . \quad . \quad . \quad . \quad (3)$$

Hence, if $a=a_0/(1+a_0p_0)$ and $\vartheta=\vartheta_0/(1+a_0p_0)$, equation (3) at once reverts to the form (2). Thus from the observations y made along any arc of the whole curve, between $p=0$ and $p=p$, it is at once possible to obtain the constants for the whole curve referred to an origin at zero atmospheres, by the equations

$$a_0=a/(1-ap_0) \text{ and } \vartheta_0=\vartheta/(1-ap_0) \quad . \quad . \quad . \quad . \quad (4)$$

so that the reductions are simple. Equations (4) suggest an important consequence: when $ap_0>1$, both a_0 and ϑ_0 become imaginary. It is a matter for curious remark, that this takes place in case of ether and of alcohol, near or above the critical temperature. I inferred that the compressibility of liquids $d\frac{v}{V}/dp=-\vartheta/(1+ap)$ changes form and passes into the compressibility of gasses $\frac{dv}{v}/dp=-1/p$, through an imaginary form.

When p is small, $y=\vartheta p(1-ap/2)$, which will be further simplified in the next paragraph.

The expression for compressibility has a counterpart* which is applicable for thermal expansion, viz:

$$d\frac{v}{V}/d\theta=\tau/(1-\beta\theta).$$

This application must be omitted here.

Finally the change of p when regarded as a function of the radius ρ of any unit sphere within the compressed liquid is of interest. It appears that $p=(e^{a(1-\rho^3)/\vartheta}-1)/a$. This equation points out the nature of the inadequacy of (2); for if ρ decreases indefinitely, p eventually becomes $(e^{a/\vartheta}-1)/a$. In the next paragraph a/ϑ is found to be nearly 9. Hence the limit in question is $8290/a$. In the cases where (2) applies this value lies somewhere between 10^6 and 10^7 atmospheres. Hence the interval within which (2) may apply satisfactorily is reasonably large; for the pressures stated are such as would be met with at the center of the earth for instance.

29. *Direct computation.*—After the suggestions contained in § 27, approximate values for the constants in the equation $v/V=ln(1+ap)^{\vartheta/a}$ are easily derived.† Constants thus obtained are crude. Hence starting with these, I computed more accurate data by a method of gradual approximation, finally selecting such values of ϑ and a as reduced the errors to a reasonably small amount. This computation is exceedingly tedious and unsatisfactory at best, because pairs of values of ϑ and a differing very widely from each other, are often found to satisfy the equation about equally well. Nevertheless it was necessary to avoid any scheme of selection other than the criterion of errors specified, the object being to obtain a set of exponential constants independent of ulterior purposes or considerations. The results are given in table 21, in which the first column contains the initial pressure p_0 for which ϑ and a apply at the temperature θ. The table also contains the ratio $2{\cdot}3\ \vartheta/a$, the factor reducing it to common logarithms. At the end of the table I have added the mean datum $2{\cdot}3\ \vartheta_0/a_0$, derived from all the values of the table.

30. *Investigation of mean constants.*—The tabulated constants for ether and alcohol above 185°, substantiate the remarks made in § 28, relative to the limited high temperature application of $v/V=ln\,(1+ap)^{\vartheta/a}$. The critical temperatures

* Applying this equation to the isopiestics of ether between 30° and 310°, I found the observations well reproduced, in a way to include the remarkable volume changes at and above the critical temperature.

† Reference to y is conveniently dropped here.

of these substances are 195° and 234°, respectively. Hence ether shows an imaginary ϑ_0 even at 185°, and both liquids do so at 310°.

TABLE 21.

Exponential constants. Direct computation.

Substance.	θ	$\vartheta \times 10^6$	$a \times 10^3$	$10^3 \times 2{\cdot}3\,\vartheta/a$	Substance.	θ	$\vartheta \times 10^6$	$a \times 10^3$	$10^3 \times 2{\cdot}3\,\vartheta/a$
Ether	310	31800	280	261	Benzoic				
$p_0=100$	185	1130	12·0	217	Acid	185	140	1·4	230
	100	361	3·8	218	$p_0=20$				
	65	225	2·0	259	Paraffine	310	362	3·2	260
	30	167	1·6	240	$p_0=20$	185	180	1·8	231
Alcohol	310	15000	140	247		100	113	1·1	232
$p_0=150$	185	351	3·9	207		65	89	·8	256
	100	164	2·0	189	Thymol	310	466	4·7	230
	65	116	1·2	223	$p_0=20$	185	163	1·6	234
	30	88	·6	336		100	100	1·2	191
Palmitic Acid	310	332	3·0	250		65	74	·7	243
$p_0=20$	185	160	1·5	245		28	65	·6	248
	100	104	1·0	238	Monobrom	185	121	1·0	280
	65	89	.8	257	Camphor	100	82	·5	376
Para-	310	421	4 5	215	$p_0=20$				
Toluidine	185	145	1·7	196	α-Naphtol	185	86	·8	246
$p_0=20$	100	82	·4	470	$p_0=20$	100	63	·7	207
	65	68	·5	315	Vanilline	185	96	·9	235
	28	57	·3	440	$p_0=20$	100	59	·5	271
Diphenyl-	310	216	2·0	248	Azo-Benzol	185	130	1.2	250
amine	185	113	1·2	217	$p_0=20$	100	80	·8	229
$p_0=0$	100	68	·5	311					
	65	62	·3	470	Mean $2{\cdot}3\vartheta/a=·257\pm·008$				
Caprinic Acid	---	----	---	---	$\vartheta/a=·1119=1/9$ nearly.				
$p_0=20$	185	201	1·9	243					
	100	114	1·0	263					
	65	92	·7	303					
	30	77	·7	252					

The last column $2{\cdot}3\,\vartheta/a$ is of special interest. Looking at these results as a whole and taking the enormous range of variation fully into account, it appears that ϑ and a are not only closely related, but that this relation is linear. The values $2{\cdot}3\,\vartheta/a$, though frequently irregular show no consistent grouping It is also to be remembered that the computation of table 21 was an entirely independent procedure. Values more nearly in keeping with the mean ratio ϑ/a could easily have been obtained had I entered into the work with any bias. Hence it is justifiable to regard the equation

$$v/V = ln\,(1+9\vartheta p)^{1/9}$$

as applicable to the whole series of organic substances examined. With this point of departure I made a recalculation of ϑ, and have inserted the results in tables 4 to 14 above. Table 22 contains additional substances.

TABLE 22.

Mean exponential constants. $v/V = ln\,(1+9\vartheta p)^{1/9}$.

Substance.	θ	$\vartheta \times 10^6$	$\vartheta_0 \times 10^6$	$1/\vartheta_0$	Substance.	θ	$\vartheta \times 10^6$	$\vartheta_0 \times 10^6$	$1/\vartheta_0$
Ether	29	165	194	6060		310	366	392	2550
p_0=100	65	226	282	4420	Paraffine	65	-----	†100	10000
B. P.=34°	100	343	497	2910	p_0=10	100	-----	118	8470
	185	1005	10060	990		185	-----	186	5380
	310	34250	*	290	*a* Naphtol.				
Alcohol	28	89	101	11240	p_0=20	100	62	62	16130
p_0=150	65	115	136	8700	M. P.=94°	185	85	87	11490
B. P.=78°	100	158	201	6330	B. P.=280°				
	185	331	598	3020	Thymol.	28	65	66	15150
	310	13830	*	720	p_0=20	64	74	75	13330
Palmitic	65	91	93	10750	M. P.=53°	100	96	97	10310
Acid	100	102	104	9610	B. P.=233°				
p_0=20	185	160	165	6060		185	161	166	6020
B. P.=350°	310	330	351	285		310	448	487	2050
M. P.=62°					Monobrom				
Para	28	59	60	16670	camphor	100	83	85	11760
toluidine	65	68	69	14490	p_0=20	185	123	126	7940
p_0=20	100	87	88	11360	M. P.=76°				
B. P.=198°	185	138	142	7040	B. P.=274°				
M. P.=43°					Azo-				
	310	392	422	2370	Benzol	100	79	80	12500
Diphenyl-	65	65	65	15380	p_0=20	185	131	134	7460
amine	100	69	69	14490	M. P.=68°				
p_0=0	185	110	110	9090	B. P.=293				
M. P.=54°	310	213	213	4690	Vanilline				
B. P.=310°					p_0=20	100	58	58	17240
Caprinic	30	76	76	13160	M. P.=80°	185	92	93	10750
acid	65	95	97	10310	B. P.=285°				
p_0=20	100	119	121	8260	‡Naphtha'ne	100	93	97	10310
M. P.=30°					p_0=50	153	115	121	8260
B. P.=270°	185	200	207	4830	M. P.=80°	185	133	141	7090
Benzoic acid					B. P.=215°				
p_0=20	185	138	141	7090	‡Monochlor-				
M. P.=121°					acetic acid	65	-----	72	13900
B. P.=249°					p_0=0	185	-----	142	7040
Paraffine	64	88	†89	11240	M. P.=62°				
p_0=20	100	111	114	8770	B. P.=188°				
M. P.=55°	185	178	184	5430					

31. *Subsidiary inferences.*—If $1/\vartheta_0$, the resistance to compression, be constructed as a function of temperature, θ, it will be seen that except in the extreme cases of ether and alcohol, $1/\vartheta_0$ decreases nearly proportional to θ, at a rate nearly the same for all the substances examined. Again if the values of ϑ at melting points and boiling points be found, no perspicuous relation is discernable. This substantiates the remarks of § 27. Turning to tables 4 to 14 it appears by consulting the difference columns, that the errors of v/V are

* Imaginary. Reciprocals of ϑ are taken. † Solidification.
‡ Results of an older method.

within the range of accuracy specified in the critical paragraphs 9 to 15.

TABLE 23.

Isothermals of Ether, referred to unit of volume at 28° and 100 atm.

$\theta=$	*310°	185°	100°	65°	28°	Isometrics. θ	Isometrics. Δp	Isometrics. Volume.
$p=0$	----	----	----	----	----	28°	0	1·00
100	2·77	1·397	1·131	1·057	1·000	65	310	
200	1·70	1·298	1·097	1·035	·984	100	600	
300	1·50	1·236	1·071	1·017	·971	185	1300	
400	1·38	1·193	1·049	1·001	·959	Rate ·12° per atmosphere.		
500	1·29	1·159	1·030	·987	·948			
600	1·22	1·132	1·014	·974	·938			
700	1·16	1·109	1·000	·963	·929			
800	1·12	1·088	·986	·953	·921			
900	1·08	1·069	·975	·944	·913			
1000	1·04	1·053	·964	·935	·906			
1100	1·01	1·039	·955	·927	·899			
1400	·93	1·001	·929	·904	·881			
1600	·88	·983	·914	·893	·870			

TABLE 24.

Isothermals of alcohol, referred to unit of volume at 28° and 150 atm.

$\theta=$	310°	185°	100°	65°	28°	Isometrics. θ	Isometrics. Δp	Isometrics. Volume.
$p=0$	----	----	----	----	----	28°	0	1·0
150	2·29	1·229	1·087	1·035	1·000	65	367	
250	1·63	1·193	1·071	1·024	·991	100	740	
350	1·47	1·165	1·057	1·014	·983	185	1470	
450	1·37	1·142	1·044	1·004	·976	Rate ·10° per atmosphere.		
550	1·29	1·122	1·033	·996	·969			
650	1·24	1·105	1·022	·988	·963			
750	1·19	1·089	1·013	·980	·956			
850	1·16	1·075	1·004	·973	·951			
950	1·12	1·063	·995	·966	·945			
1050	1·09	1·051	·988	·960	·940			
1150	1·06	1·041	·980	·954	·935			
1450	1·00	1·013	·961	·938	·921			
1650	·96	0·997	·949	·928	·912			

32. *Isothermals computed.*—From these results the actual isothermals of the above substances can be constructed. To recapitulate: the volume decrement $v/V=ln(1+9\vartheta p)^{1/9}$, refers in all cases to unit of volume at the temperature of the isothermal and under the initial pressure p_0. The compressed volume is therefore $1-ln\,(1+9\vartheta p)^{1/9}$; and if in consequence of the *observed* thermal expansion at p_0, the volume at θ be v_θ, the actual isothermal is

* Special measurement, made later.

$$v_{\theta p}=v_\theta(1-ln(1+9\cdot9p)^{1/9}) \quad \ldots\ldots\ldots \quad (5)$$

referred to the initial temperature θ_0. v_θ is directly measured. Hence the only hypothesis occurring in equation (5) is equation (2). In tables 23 to 28 I have given the value of $v_{\theta p}$ computed conformably with equation (5), for the temperatures of observation. If these results be constructed graphically, the conditions subject to which pressure and temperature must vary, in order that $v_{\theta p}$ may remain constant are given by drawing horizontals. In the supplementary tables certain isometric data are inscribed.

TABLE 25.

Isothermals of Diphenylamine, referred to unit volume at 65° and 0 atm.

$\theta=$	310°	185°	100°		Isometrics.		
					θ	Δp	
$p=$ 0	1·235	1·093	1·012	1·000	65	0	1.00
100	1·211	1·082	1·006	·994	100	190	
200	1·191	1·071	·999	·988	185	1200	
300	1·173	1·061	·993	·982			
400	1·157	1·053	·988	·977	Rate ·09° per atmosphere.		
500	1·143	1·044	·982	·971			
600	1·130	1·036	·976	·967			
700	1·119	1·029	·972	·962			
800	1·108	1·022	·967	·957			
900	1 098	1·016	·962	·953			
1000	1·089	1·010	·958	·949			
1300	1·064	·993	·945	·937			
1500	1·050	·983	·938	·930			

TABLE 26.

Isothermals of Thymol, referred to unit volume at 20° and 20 atm.

$\theta=$	310°	185°	100°	65°	28°	Isometrics.		
						θ	Δp	Volume.
$p=$ 20	1·329	1·162	1·076	1·042	1·000	65	40	1·04
120	1·279	1·145	1·066	1·035	·994	100	410	
220	1·242	1·129	1·057	1·028	·988	185	1090	
320	1·212	1·116	1·049	1·021	·982	310	1500	
420	1·188	1·103	1·041	1·015	·977			
520	1·167	1·092	1·033	1·009	·972	Rate ·11° per atmosphere.		
620	1·148	1·081	1·026	1·003	·967			
720	1·131	1·072	1·020	·998	·962			
820	1·116	1·064	1·013	·993	·957			
920	1·103	1·055	1·007	·988	·953			
1020	1·091	1·047	1·002	·983	·949			
1320	1·059	1·026	·986	·970	·937			
1620	1·040	1·014	·977	·961	·930			

33. *Isometrics.*—Some remarks on these tables are essential. In case of alcohol the curves for 28° to 185° are a family of

like properties. The curve for 310° intersects these at high pressure. This, however, was suggested in § 28, since above the critical temperature the *mean* equation (2), is not applicable. The chief result of the table is given in the supplement, for $v_{\theta p}=v_{28,150}=1$. It appears that θ and p as far as 185°

TABLE 27.

Isothermals of Paraffine, referred to unit volume at 65° and 20 atm.

$\theta=$	310°	185°	100°	65°	Isometrics.		
					θ	Δp	Volume.
$p=$ 20	1·241	1·108	1·026	1·000	65	0	1·00
120	1·202	1·090	1·015	·991	100	250	
220	1·171	1·074	1·005	·983	185	880	
320	1·146	1·060	·996	·975	310	1430	
420	1·125	1·047	·988	·968	Rate 1·3° per atmosphere.		
520	1·107	1·036	·980	·962			
620	1·091	1·025	·973	·956			
720	1·076	1·016	·966	·950			
820	1·063	1·007	·959	·945			
920	1·051	·999	·953	·939			
1020	1·040	·991	·947	·935			
1320	1·012	·970	·931	·921			
1520	·995	·958	·922	·912			

TABLE 28.

Isothermals of Para-Toluidine, referred to unit volume at 28° and 20 atm.

$\theta=$	310°	185°	100°	65°	28°	Isometrics.		
						θ	p	Volume.
	----	----	----	----	----	65	25	1·04
$p=$ 20	1·348	1·158	1·063	1·042	1·000	100	270	
120	1·303	1·143	1·054	1·035	·994	185	1200	
220	1·268	1·130	1·046	1·028	·989	Rate ·10° per atmosphere.		
320	1·240	1·117	1·038	1·022	·983			
420	1·216	1·106	1·030	1·017	·978			
520	1·196	1·096	1·023	1·011	·973			
620	1·178	1·087	1·017	1·006	·969			
720	1·162	1·078	1·011	1·001	·965			
820	1·147	1·069	1·005	·996	·960			
920	1·134	1·062	1·000	·992	·956			
1020	1·122	1·055	·994	·987	·952			
1320	1·090	1·035	·979	·974	·941			
1520	1·072	1·023	·970	·967	·934			

are linear functions of each other. The rate of change is ·10° C. per atmosphere.

Similar remarks apply for ether, where conformably with the lower critical point, the high temperature discrepancy is more pronounced. The rate of variation of θ and p for $v_{\theta p}=v_{28,100}=1$ is here ·12° per atmosphere.

In case of paraffine, which is the first substance solid at ordinary temperature, $v_{\theta p}=1$ shows a somewhat larger variation of θ relative to p, the rate being ·13° C. per atmosphere. The rate for thymol is ·11° per atmosphere, for toluidine ·10° per atmosphere, for diphenylamine ·09 per atmosphere. In most of these cases the expansion difficulties, § 14, make the present results irregular, particularly in the case where two or more threads are observed. At 310° the behavior is usually exceptional, the discrepancy which shows itself is similar to the case of ether and alcohol, but much less pronounced.

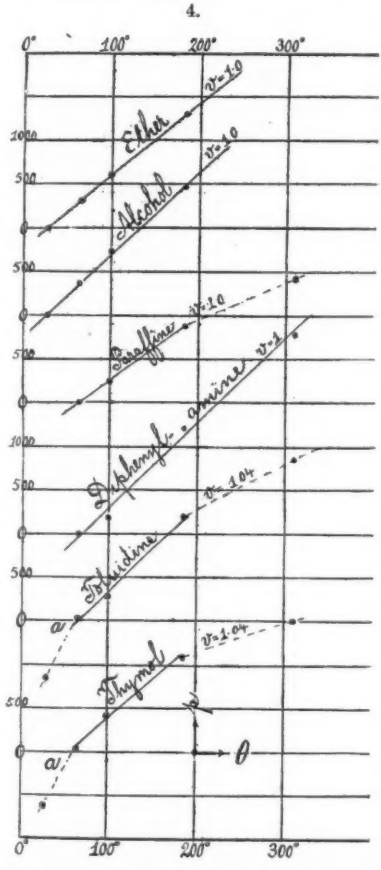


Fig. 4. Isometrics of Ether, Alcohol, Paraffine, Diphenylamine, Toluidine and Thymol.
a, region of undercooling.

In figure 4 I have represented these relations graphically. It is seen at once that the errors left show no march. For diphenylamine the distribution is zigzag; for toluidine and thymol in an opposite sense for the two cases.

Taking these results (0° to 185°) as a whole it follows with remarkable uniformity that if temperature and pressure vary linearly with each other, at a rate of about ·1° C. per atmosphere, there will be no change of volume. More rigorously: *if with the observed thermal expansion compressibility be supposed to increase inversely as the first power of the pressure binomial* (§ 27), *then temperature and pressure must vary linearly to maintain constancy of volume.* Change of the state of aggregation is excluded. The thermodynamic signification of this result has been suggested in § 2. So far as the present results go, 0° to 185°, the

surface $v_{\theta p}$ will be generated by moving the initial section, when θ is constant, parallel to itself, in such a way that each point describes an oblique horizontal. It is not to be inferred that these horizontals are parallel, though within the limits of the above investigation such a result is nearly given.

Compressibility increasing inversely as the square of the pressure binomial.

34. *Properties of the equations.*—Equation (2) as used in § 27, furnished a family of curves which in their ultimate contour necessarily fall below the corresponding isothermals of the substance under discussion. It is the object of this section to investigate a similar family, the ultimate contours of which are above the actual isothermals. This may be done by assuming $d\frac{v}{V}/dp=\mu/(1+\nu p)^2$, whence

$$v/V=\mu p/(1+\nu p) \quad . \quad . \quad . \quad (6)$$

In this case, when $p=\infty$, $v/V=\mu/\nu=2/9$, as will be seen in the following tables. In the actual case,* v/V, though it can not be greater than 1, will in all probability eventually exceed 2/9.

The method of discussion to be adopted is similar to that in the foregoing section. Let

$$y_0=\mu_0 p_0/(1+\nu p_0) \text{ and } y'=\mu_0(p_0+p)/(1+\nu(p_0+p)).$$

Then $y=y'-y_0=\mu_0 p/((1+\nu_0 p_0)^2(1+\nu_0 p)/(1+\nu_0 p_0))$; or if

$$\mu=\mu_0/(1+\nu_0 p_0)^2 \text{ and } \nu=\nu_0/(1+\nu_0 p_0) \quad . \quad (7)$$

equation (6) again results. Hence if p_0 and p are consecutive pressure intervals between 0 and $p+p_0$, then the constants obtained from observations within the interval p, may be reduced to those applying to the whole interval p_0+p, by equations (7), or their equivalents

$$\mu_0=\mu/(1-\nu p_0)^2, \quad \nu_0=\nu/(1-\nu p_0) \quad . \quad . \quad (8)$$

According to Mendeleef, Thorpe and Rücker, (l. c.), the volume of liquids in case of thermal expansion may be represented by $V_\theta=1/(1-k\theta)$, where pressure is constant, V_θ the actual volume at temperature θ, and k a constant. Introducing equation (6) and denoting by V, the volume for pressure p and temperature θ, $V=(1+(\nu-\mu)p)/(1-k\theta)(1+\nu p)$, which for pressures and temperatures not too great may be put $V=1+(\nu-\mu)p/(1-k\theta+\nu p)$. If, therefore, $V=V_c$ is constant,

* Cf. Rücker (Nature, xli, p. 362, 1890). Converging lines of evidence obtained from optical, electrical and thermal researches show that liquids can not be compressed more than ·2 to ·3 of their normal bulk.

$\theta=-(1-V_c)/kV_c+p(\nu(1-V_c)-\mu)/kV_c$; so that in case of constant volume, temperature varies linearly with pressure, small intervals of variation presupposed. The rigorous deduction from (6) and Mendeleef's equation is $kV_c\theta=-(1-V_c)+\mu p/(1+\nu p)$, which is linear in proportion as νp is small compared with 1. In § 33 it was shown that the relation of θ and p is probably linear throughout great intervals. It follows that (6) is insufficient for large ranges of pressure. Finally regarding Mendeleef's equation, it follows, if θ_0 and θ be two consecutive intervals of temperature, the former measured from zero, that $V_0=1/(1-k_0\theta_0)$, $V_\theta'=1/(1-k_0(\theta_0+\theta))$, and $V_\theta=1+V_\theta'-V_0=(1+k^2\theta\theta_0)/(1-k\theta)$, if $k=k_0/(1-k_0\theta_0)$. Thus observations may be referred to any convenient temperature as a point of departure.

35. *Computation of hyperbolic constants.*—Applying equation (3) to the observations in § 15 to 24, I obtained the constants given in table 29. Clearly ν must be some function of μ; but the observations are now too crude to indicate its nature. If the ratios of ν to μ be found either graphically or by computation, the consecutive values show no discernable march or grouping. Hence I assume this ratio to be constant, and add its mean value in the table. As before the ether and alcohol points at 310° are to be excluded, and the discrepancy is apparent in the ether point for 185°.

TABLE 29.

Hyperbolic constants. Direct computation.

θ	$\mu\times10^6$	$\nu\times10^6$	θ	$\mu\times10^6$	$\nu\times10^6$	θ	$\mu\times10^6$	$\nu\times10^6$
Ether			Toluidine			Paraffine		
29	169	830	28	56	58	65	85	191
65	228	1030	65	70	413	100	111	475
100	353	1570	100	81	110	185	181	845
185	1028	3870	185	146	801	310	368	1510
Alcohol			310	401	1730	Thymol		
28	87	243	Diphenylamine			28	68	465
65	111	276	65	61	162	65	69	157
100	182	1630	100	69	285	100	99	553
185	348	1755	185	114	613	185	162	715
			310	215	889	310	465	2000

Mean $\nu/\mu=4{\cdot}5$.

36. *Mean constants.*—Utilizing the ratio $\nu/\mu=4{\cdot}5$, I constructed the next table. The agreement as a whole is not as good as were the data for ϑ and a in § 30.

37. *The isothermal band.*—With the constants of table 30, I computed the actual isothermals, in the way suggested in § 32. Expansion being directly observed, the only hypothesis introduced is equation (6). The results so obtained are to be tabulated in the manner shown in tables 23 to 28, with which they

are to be compared. The two sets of results then exhibited the upper and the lower limit of the isothermal band, § 25. I will omit the new results here and confine myself to a statement of the degree of accordance.

TABLE 30.

Hyperbolic constants. Mean values. $v/V=\mu p/(1+4{\cdot}5\ \mu p)$.

Substance.	θ	$\mu\times10^6$	Substance.	θ	$\mu\times10^6$
Ether	29	167	Diphenylamine	65	64
	65	229		100	69
	100	354		185	112
	*185	1220		310	216
Alcohol	28	89	Paraffine	65	88
	65	115		100	112
	100	163		185	181
	185	340		310	382
Para-Toluidine	28	59	Thymol	28	66
	65	69		65	73
	100	86		100	97
	185	141		185	162
	310	412		310	481

* Equation begins to fail.

In case of ether the divergence, or the width of the band at 1000 atm. is ·4 per cent at 28°, 1 per cent at 65° and at 100°. At 185° the hyperbole begins to fail. Constructing the isometrics for p and θ, when $V_c=1$, it is seen that whereas for the exponential formula (2) the straight line is predicted as far as 185° and 1300 atm., this is not the case with the hyperbolic equation, for which the isometrics are straight only below 100° and 700 atm.

The conformity of results for alcohol is better throughout. At 1000 atm., the divergence at 28° is nil; at 65° it is 2 per cent; at 100°, ·3 per cent; at 185°, 2 per cent. When $V_c=1$, the exponential relation is satisfied by linear isometrics as far as 185° and 1500 atm. The hyperbola admits of this only below 100° and 700 atm.

Divergences in case of paraffine at 1000 atm. is ·1 per cent at 65°, ·2 per cent at 100°, ·7 per cent at 185°, 6 per cent at 310°. As far as 185° and 900 atm. both isometrics are linear. At 310° both show curvature, toward opposite sides of the common line. The exponential is in better agreement. The divergence at 1000 atm. in case of diphenylamine is ·1 per cent at 65° and at 100°, ·2 per cent at 185°, 1 per cent at 310°. The linear isometrics hold almost to 310°. Thymol at 1000 atm. shows a divergence of ·1 per cent at 28°, ·2 per cent at 65°, ·1 per cent at 100°, ·6 per cent at 185°, 3 per cent at 310°. Finally, para-toluidine at 1000 atm. shows a divergence of nil at 28° and 65°, ·3 per cent at 100° and at 185°, 3 per cent at 310°.

38. *Conclusion.*—Summarizing these results it appears that the exponential $v/V=ln(1+ap)^{a/\vartheta}$ is more in keeping with the general character of the isothermals discussed than is the hyperbolic form $v/V=\mu p/(1+\nu p)$. Both equations *apparently* fail at 310°. It is difficult to assign a reason for this. It is not probably due to occluded air, since the substances were boiled and introduced into a hot capillary tube. Moreover in case of mercury (table 3) an air bubble discrepancy would necessarily have shown itself at 310°. Errors due to the fact that my curves must be in some small measure isentropic, would induce too slow a volume variation and hence only emphasize the break. There may be dissociation in some of the above organic substances at this high temperature. Azobenzol actually decomposes and turns black at 310°. What the effect of dissociation may be in modifying the computed isothermal is not easily conjectured; for the greater compressibility of the dissociated substances is in some degree compensated by larger initial volumes. Equation (2), however, must certainly begin to fail. Cf. § 28.

The high temperature break in question would result in case of inconstancy of temperature in the boiling tube. I did not test the thermal distribution; the behavior was such throughout that I see no reason to suspect inconsistency. Final reference might be made to the pressure expansion of the capillary tube.

To throw light on these particulars, I made the following direct measurements with ether, a case in which the high temperature break is most pronounced. Table 31 contains an example of the results. The isothermal are referred to unit of volume at 22° and 100 atm. To reduce them to 29° and 100 atm., conformably with table 23, the volumes at 310° are to be decreased 1·5 per cent. The length of thread at 22° is only 1·85^{cm}, thus enabling me to observe the whole thread at 310°. In other respects the work was done in the manner indicated above to make the different data comparable.

TABLE 31.

Isothermals of Ether. Direct measurement.

$\theta=300°$; $L_{100}=6·00^{cm}$

p	Volume.	Volume.	p	Volume.	Volume.	p	Volume.	Volume.
atm.			*atm.*			*atm.*		
100	3·30	3·12	400	1·43	1·41	700	1·24	1·23
200	1·83	1·76	500	1·34	1·32	800	1·19	1·19
300	1·56	1·52	600	1·28	1·26	900	1·16	1·16
			$\theta=22°$; $L_{100}=1·84^{cm}$					
100	1·00	1·00	300	·97	·97			
200	·99	·99	400	·96	·96			

Constructing the isometric for $V_{\theta,p}=V_{2\vartheta,100}=1$, it will be seen that the 310° point may be looked for in the region above 2000 atm. Hence, these observed results substantiate the computed isometric in figure 4, which predicts the corresponding point at 2300 atm. Nevertheless it cannot be too carefully noted, that if the isometrics for $V_{\theta,p}=1{\cdot}2, 1{\cdot}3, 1{\cdot}4, \ldots$ be constructed the break between 185° and 310° remains in full force, quite in conformity with the other data (alcohol, paraffine, etc.).

The full interpretation of these discrepancies is of great importance and will therefore be made the subject of my subsequent work. The isometric, curved as above, introduces certain interesting conditions of maximum volume.

The chief observational discrepancy remaining in the results is the expansion error encountered in case of substances which solidify between observations at different temperatures. Hence the effect of different volumes on the slope of the isometrics cannot be satisfactorily discussed. Since the compression measurements retain their value independent of the thermal expansion, and since the method pursued is such that all necessary measurements for thermal expansion can be made under atmospheric pressure, the difficulties may easily be rectified. For by using a bulb and stem arrangement, the purely thermal data can be supplied with any desired accuracy. This I conceive to be the advantage of the mode of investigation set forth in the present paper.

Among the important results of the above tables is the fact that compressibility moves in the even tenor of its way quite independent of normal boiling points and melting points, provided of course the conditions are not such that boiling or melting can actually occur. For this reason compressibility is particularly adapted for exploring the nature of the environment of the molecule in its relations to temperature, i. e. for exhibiting the character of the thermal changes of the molecular fields of force.

The above work though confined to relatively low ranges of pressure was believed to have a more general value for reasons such as these: instead of tracing the isothermals of a single substance throughout enormous ranges of pressure, similarly comparable results may possibly be obtained by examining different substances, conceived to exist in as widely different thermal states as possible. For in such a case, since the actual or total pressure is the sum of the pressures externally applied and the internal pressure, the total pressure in question virtually varies enormously. This calls to mind the remarks made in §§ 28, 34, relative to observations confined to a limited part of the isothermal.

Finally the work of the present paper may be looked at from quite a different point of view. Suppose for instance, I regard the linear isometric proposed by Ramsay and Young (l. c.) as an established fact. Then the chief result of the present work, viz: that the exponential equation (2) if applied to the observed changes of volume predicts a linear isometric throughout an enormous range of pressure, affords favorable evidence of the truth of the exponential equation in question. In other words, it is probable that along any isothermal compressibility increases inversely as pressure increased by a constant. The interpretation of this constant cannot now be given.

Since the above work was done, I have succeeded in constructing a screw compressor,* by aid of which 2000 atm. may be hydrostatically applied with facility. I have also constructed gauges suitable for the accurate measurement of such pressure. The general adjustment is of a kind that all necessary electric insulation of different parts of the apparatus is guaranteed, so that most of the measurements may be made electrically. With these advantages I hope to subject the data which the above pages have tentatively outlined, to a direct and more searching test.

Phys. Lab. U. S. G. S., Washington, D. C.

ART. LVII.—*On Hamlinite, a new rhombohedral Mineral from the Herderite locality at Stoneham, Me.;* by W. E. HIDDEN and S. L. PENFIELD.

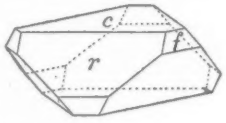
SHORTLY following the announcement of herderite† from Stoneham, the mineral, which we are about to describe, was detected by one of us occurring as minute rhombohedral crystals attached to the herderite and margarodite and associated with a mineral which was subsequently identified as the rare beryllium silicate, bertrandite. As the crystals were observed on only a single specimen and would not have weighed much more than 0·01 gram, if they could have been successfully detached from the matrix, it seemed imperative that more material should be obtained before commencing any investigation. During the past five years, therefore, we have kept up a diligent search for the crystals, examining carefully every available herderite specimen; we have also informed various

* A description of this apparatus will be found in the Transactions of the American Academy of the present year. I have now done much work with ether, tracing the isometrics directly as far as 1850 atm. and something over 215°, without however being able to reach a decision. May, 1890.

† This Journal, III, xxvii, pp. 73 and 135, 1884.

mineralogists of the occurrence of a probably new rhombohedral mineral, requesting them to examine the specimens in their own collections, but as up to the present time no success has attended our efforts we feel warranted in giving as complete a description as possible of the material in hand. We hope that in the future sufficient material may be obtained for a complete chemical investigation. We shall, moreover, consider it a great favor if the readers of this article will carefully examine the specimens of herderite which may be in their possession and aid us in securing the necessary material.

The system of crystallization is hexagonal-rhombohedral. The crystals vary from one to two millimeters in diameter and are quite flat from the predominance of the basal pinacoid. They exhibit the forms *c*, 0001, O; *r*, $10\bar{1}0$, 1 and *f* $02\bar{2}1$,–2, which are developed as shown in the accompanying figure. All of the planes are more or less uneven, especially *r*, which always yielded a number of reflections of the signal, so that it was quite impossible to obtain accurate measurements from them. The angle which was selected as fundamental was $f \wedge f$, $2\bar{2}01 \wedge 02\bar{2}1 = 108° 2'$ from which the length of the vertical axis $\dot{c} = 1{\cdot}135$ was calculated.



Other measurements resulted as follows:

		Measured.	Calculated.
$r \wedge r$,	$10\bar{1}1 \wedge 01\bar{1}1 =$		87° 2′
$c \wedge r$,	$0001 \wedge 10\bar{1}1 =$	about 55°	52° 40′
$c \wedge f$,	$0001 \wedge 02\bar{2}1 =$	69° 15′ — 70° 30′	69° 7½′
$f \wedge r$,	$02\bar{2}1 \wedge 10\bar{1}1 -$	53° 35′ — 54° 27′	54° 1′

The cleavage is perfect parallel to the base. The luster on the basal plane is pearly and on the rhombohedral faces is greasy vitreous, very similar to that of herderite. Some of the crystals are transparent and colorless, others show a faint yellow tint, owing probably to some impurity. Crystals lying on a basal plane, when examined under the microscope in convergent polarized light, show a perfectly normal, uniaxial interference figure, with positive and not very strong double refraction.

The hardness is 4·5. Specific gravity taken with the barium-mercuric iodide solution was 3·228.

Before the blowpipe the mineral fuses at about 4 to a white porcelain-like mass, coloring the flame pale green (P_2O_5). In the closed tube it gives abundant water which is strongly acid and etches the glass (F). It is slowly soluble in acids and gives with ammonium molybdate a strong P_2O_5 reaction. With H_2SO_4 it gives no micro-chemical reaction for Ca. The presence of P_2O_5 interfered with making the ordinary micro-chemical reac-

tions, but a few tests, made on two small crystals by the usual analytical methods, indicate that alumina is probably present, while, from its association with herderite and bertrandite, beryllium may be expected. We have, therefore, undoubtedly a new species, a phosphate (probably of beryllium and aluminum) containing fluorine, and one which promises to be of unusual interest. As it seems best to designate the mineral by a distinctive name we propose for it the name *Hamlinite*, in honor of Dr. A. C. Hamlin of Bangor, Me., whose life-long interest in the development of the mineral resources of his state, and particularly of Oxford County (where this new mineral occurs), has tended to make that region famous as affording some of the most beautiful and highly interesting minerals known to science.

It is to be hoped that the mineral developments now going on in Oxford County will bring to light an abundant supply of this mineral, or enough, at least, to enable us to determine its chemical composition.

April 23d, 1890.

ART. LVIII.—*On a large spring-balance Electrometer for measuring (before an audience) specific inductive capacities and potentials;* by ALFRED M. MAYER.

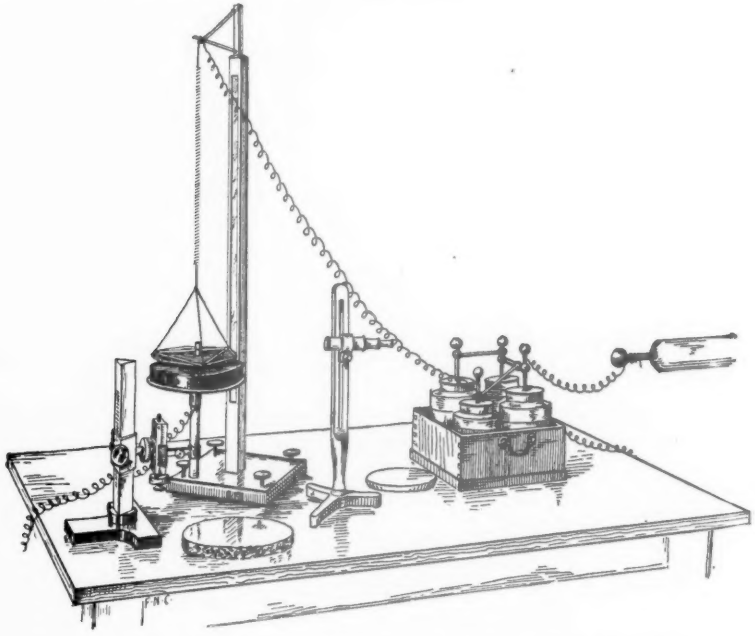
THIS apparatus was devised by me for showing to my classes the general phenomena of induction through various dielectrics, and for making approximate measures of their specific inductive capacities. These phenomena and measurements are rarely shown to students, and when their exhibition is attempted the actions on the apparatus used are generally too minute to be seen by a class, and hence the measures deduced from these actions are unsatisfactory.

The apparatus here described has done excellent service during five courses of lectures. Its chief characteristic is that it shows *directly*, and not inferentially, that different dielectrics transmit the force of electricity in different degrees.

The engraving gives a general view of the apparatus. A helical spring, made of brass wire of ·012 in. diameter and with 800 turns, is supported by a bracket formed of rods of glass. These rods were dried by heating in a gas-flame and while hot were coated with parafin. To the lower end of the spring is suspended a disc of thin mica 16½ c.ms. in diameter, silvered on its upper and lower surfaces in a silvering solution. This disc, which was nearly flat, was made rigid and as nearly flat as possible, by cementing (under pressure) to its upper surface

nine light and straight rye straws. Six of these formed chords of 60°, the other three formed an equilateral triangle included by the hexagon. This prevents flexure of the plate when it is suspended at three points by the fine wires shown in the figure. This silvered disc is surrounded by a guard-ring supported on three paraffined glass rods. The ring and rods are not shown in the figure.

Under the silvered disc and parallel to it is a brass plate connected with the earth, and moveable up and down by means of a rack and pinion and a micrometer-screw. In ordinary work



before a class the micrometer-screw is not required. The *difference* between the distances of the earth-plate from the mica-disc is only required in the measurement of specific inductive capacity, and this difference can be measured accurately enough by means of a millimeter scale cut on the column of the support of the earth-plate.

A tube of thin glass is cemented at the center of the top of the mica disc. On this tube is pasted a piece of paper with a fine line drawn on it parallel to the disc. Through the telescope on the right we sight on a horizontal thread this line,

and when the apparatus is charged we can then always depress the mica-plate to the same level, and with the same force, by gradually raising the earth-plate.

The helical spring is connected with the Leyden battery, which latter is charged with + electricity from an electrical machine. To insure a constant charge during the two measures required to determine a specific inductive capacity, a simple torsion-balance carrying a gilded pith-ball is repelled by a similar ball at the end of a rod connected with the battery. A pointer on the torsion-rod moves over a graduated arc.

To show the general phenomena of the action of a dielectric compared with air, we charge the apparatus and bring up the earth-plate till the mica-disc is sensibly depressed by the attraction existing between it and the plate connected with earth. The disc of the dielectric is now slid on the earth-plate, when every one sees a considerable depression of the mica-disc by the increased force between the two plates through the intervention of the dielectric. Or, we may reverse the operation, and first place dielectric on earth-plate, then slowly raise this plate, with dielectric, till the attraction between earth-plate and disc has caused the latter to be depressed so far that it is just above the point from which it would descend to *contact* with the dielectric. Now suddenly slide dielectric from the earth-plate. The disc at once rises through a considerable distance, which is distinctly visible throughout the lecture-room. In the case of a glass disc of 2 c.ms. thick this upward motion may amount to 3 c.ms. and after a few oscillations the mica-disc comes to rest at a distance of about 1½ c.ms. above its previous level.

To show the "electric absorption," "residual charge," "permeability," or "dielectric afterworking" (Boltzmann) of a dielectric we use a disc of paraffin. With this on the apparatus we raise the earth-plate till the mica-disc is sensibly attracted, and is stationary. This condition, however, only lasts for a short time. Soon the disc begins to descend, and after a minute or two has come near the paraffin, to whose surface it now rushes. It cannot now be detached till the battery has been discharged, or the earth-plate has been lowered so much as to unduly stretch the spring.

This experiment presents clearly a fact long known, that, with the exception of sulphur, all dielectrics, and especially paraffin are "permeated," or "polarized," in the condenser by time-action of induction, and so the attraction existing between the plates is increased. Boltzmann* shows from his experiments that with times of inductive action lasting $\frac{1}{300}$ to $\frac{1}{64}$

* Wiener, Sitzungsber., lxviii, 1873.

sec.; $\frac{9}{10}$ sec.; $1\frac{8}{10}$ sec.; and 45 secs., the specific inductive capacity of paraffin is respectively 2·32; 2·51; 2·56; and 8·12. Schiller's* experiments show that for times of charging plate-glass in the condenser of $\frac{1}{20000}$ and $\frac{1}{25}$ sec., the specific inductive capacity is respectively 5·83 and 6·34, or an increase of 9 per cent in ·03995 of a second. Wüllner† gives these conclusions from his experiments on the subject: "The instantaneous capacity (that is, the capacity when the charging lasts for a very small fraction of a second) is of quite a different nature to that capacity which increases slowly as the electrification continues. The 'instantaneous capacity' is independent of the conductivity—the 'slow capacity' is not."

To measure the specific inductive capacity of a substance, we place the guard-ring around the mica-disc. This ring has projecting from the edge of its circular opening three short fine wires, so adjusted that when the mica-disc rests on these wires the lower surfaces of disc and guard-ring are in the same plane. The apparatus having been charged, the dielectric is introduced and the earth-plate is raised till the mica-disc is attracted so that it rests on the three wires of guard-ring. The plate is now very slowly lowered till the tension of the spring just exceeds the attraction of plates, when the disc suddenly rises. The scale reading on support of earth-plate or of micrometer-screw is read. The dielectric is now removed and the disc brought down on the wires by raising earth-plate and then by lowering this plate the disc again leaves the wires, and the corresponding scale reading is taken. From the *difference* of the scale readings the specific inductive capacity is determined, as follows:

Let the scale reading when only air is between the plates be s; when the dielectric is introduced, s_1; then $s_1 - s$ is the distance the earth-plate has been moved so as to give in the two experiments the same force of attraction on the mica-disc. A dielectric of thickness t and specific inductive capacity K equals in capacity a condenser with a thickness of air between plates equal to $\frac{t}{K}$. Now when we introduce the dielectric plate it replaces a thickness of air, t. So the effect of introducing the dielectric is to increase the electric capacity of the apparatus as if we had brought the earth-plate and the mica-disc nearer by this distance t and then farther apart by the distance $\frac{t}{K}$, which is the same as if we had diminished the distance between

* Pogg. Ann., clii, 1874.
† Sitzungsb. köngl. bayer. Acad., 1877.

the earth-plate and disc by $t-\frac{t}{K}$. But as in the two experiments the force on the mica-disc is equal, we must have caused an equal *decrease* in *capacity* by increasing the distance between earth-plate and disc by the quantity $s_{,}-s$, when the dielectric intervened, and this *measured* increase of distance equals the imaginary decrease of distance produced by the dielectric, and we have $t=\frac{t}{K}(s_{,}-s)$ and $K=\frac{t}{t-(s_{,}-s)}$.*

We use a disc of sulphur about 2½ c.ms. thick as the body to experiment on in this measure before a class, as sulphur is very slightly, if at all, affected by time-induction during the interval occupied by the measure.

If the guard-plate be removed the phenomena become more apparent to the audience, but the measure is not so exact. In making measures without the guard-plate we use the telescope and the line on the glass tube, or, for ordinary qualitative illustration a pointer may replace these.

It need hardly be stated that measurements with this apparatus are of little value when compared with the measures made with the excellent apparatus of Gordon where entire control of the time of charging and means of measuring, very minute differences of capacity are used. Nevertheless the measures obtained with this apparatus are really more reliable than those obtained by some of the older experiments. The exhibition of the actions of this apparatus, however, are well worthy of being shown to students. The clear ideas and lasting impressions they give, from their directness and easy comprehension, will reward the teacher for the time he may give to the construction and use of the apparatus.

The same instrument will also measure potential, for it is really a huge and rough absolute electrometer. Certain precautions are, however, needed in its use in such measures. In the formulæ used in measurements with the absolute electrometer, $V = D\sqrt{\frac{8\pi W . g}{A}}$, or $V-V'=(D-D')\sqrt{\frac{8\pi W . g}{A}}$, one might suppose that W could be determined for the spring-balance electrometer by merely adding the weight in grams required to depress the silvered disc down to the level of the guard-plate; but, on electrifying the helical spring, its coils separate by mutual repulsion and a certain lengthening of the spring results. This action may be determined and allowed for by first ascertaining the weight of mica-disc and its wires and additional weight required to depress the disc to contact with the wires of guard-plate. The disc is now detached from

* See Gordon's Electricity and Mag., vol. i, p. 111.

the spring and placed on the guard-plate wires. On the top of the disc is a tube, in electrical connection with the disc, and containing mercury. The earth-plate is at the position it has when we are measuring potential. The spring is so stretched by a weight that the straight end of its wire dips into the mercury in the tube on the mica-disc, and the apparatus is charged to the same potential it has when we are making a measure of that potential. We now ascertain the weight required to stretch the spring to the same extent it was stretched in the previous experiment. The difference in weight required in the two experiments gives the repulsive action of the electricity on the spring. This correction, however, is not precise, for the wire at the end of spring is slightly pushed upward by the mutual action of the electrified wire and mercury.

Stevens Institute of Technology, Hoboken, N. J.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Emission-spectrum of Ammonia.*—Magnanini has examined the spectrum given by the flame of ammonia when burning in oxygen gas, and has given in a table the wave-lengths, intensities and peculiarities of the lines and bands existing in the region from wave-length 6666 to 4492. The spectrum of ammonia obtained in this way, is much richer and more complex than that obtained by means of the electric spark. On comparing the spectrum of burning ammonia with the spectra of ethylamine and trimethylamine obtained in the same way with suitable access of oxygen, it is easy to recognize in the latter besides Swan's spectrum of the burning gaseous organic compounds, the ammonia spectrum also, though its intensity is feeble. A comparison of the ammonia spectrum with the spectrum of hydrogen of the second order, shows that a large number of lines in both spectra coincide exactly so far as position goes, but do not agree either in intensity or in appearance otherwise. Whether this coincidence is real or only apparent, resulting from insufficient dispersion, must be determined by further observations.—*Zeitschr. Phys. Chem.*, iv, 435; *Ber. Berl. Chem. Ges.*, xxiii, (Ref.) 171, March, 1890. G. F. B.

2. *On the Absorption-spectrum of Nitrosyl Chloride.*—The absorption-spectrum of gaseous nitrosyl chloride, prepared by acting on sodium nitrite with phosphoric chloride in excess, has also been examined by Magnanini. The chloride was contained in a glass tube 49^{cm} long, so blown at the ends as to give nearly plane and parallel surfaces. The spectrum resembles closely that of the liquid chloride, being a band spectrum, not broken up into lines. It consists of three bands in the red, of which the middle

one is the strongest, and three bands in the green-blue, weaker than the others. From wave-length 5268 the general absorption rises to 5203, becoming total for the more refrangible region beyond this. The wave-lengths of the six bands characteristic of nitrosyl chloride are given as 6228–6133, 6063–5970, 5898–5843, 5634–5600, 5432–5581 and 5411–5363.—*Zeitschr. Phys. Chem.*, iv, 427; *Ber. Berl. Chem. Ges.*, xxiii, (Ref.) 171, Mch. 1890. G. F. B.

3. *A Dictionary of Applied Chemistry;* by T. E. THORPE, assisted by eminent contributors. In three volumes. Vol. I, London, 1890 (Longmans, Green & Co.).—In a notice of the new edition of Watts's Dictionary of Chemistry in a recent number (vol. xxxviii, 409) attention was called to the fact that the plan, that had been adopted, contemplated a companion work which should deal with the application of chemistry to the arts. The first volume of this work has now appeared, under the able editorship of Professor Thorpe and well fulfills the promises that were made for it. The subject matter differs in this case from that treated of in the work on theoretical chemistry in that the variety and mass of material is less great and hence the necessity for compression and the great amount of abbreviation does not exist, which it must be confessed is a relief to the reader. The wide range of topics has been handled by a series of workers, eminently qualified for the task they have undertaken, and the combined result of their labors with those of the chief editor is one of the best works of reference ever presented to the English-reading public, one whose completeness and accuracy leave little to be desired.

4. *Method of obtaining the oscillatory discharge used by Hertz.*—H. CLASSEN employs a blast of air which is blown between the terminals of a Ruhmkorf coil. The glow of hot particles of metal is suppressed and a sharp crackling spark suitable for the repetition of Hertz's work takes its place. A blast of steam answers the same purpose.—*Wied. Annalen der Physik*, No. 4, 1890, p. 647. J. T.

5. *Oscillatory discharge of the Ruhmkorf coil.*—M. R. COLLEY discusses the theory of the Ruhmkorf coil with reference to the problem of mutual induction. He introduces coils into the circuit in order to modify these factors and studies the character of the discharges of the Ruhmkorf coil through Geissler tubes by means of a revolving mirror. The changing nature of the stratification of the luminous tubes is an indication of the character of the oscillatory discharge. The experiments confirm the conclusions deduced from the equations of the author.—*Comptes Rendus*, March 31, 1890, p. 700. J. T.

6. *Application of Photography to the study of Superficial Tension.*—Prof. SMITH described the method, (Royal Society Edinburgh, March 17,) as follows: Ripples are set up on the surface of the liquid by means of a tuning fork and the surface is then photographed along with a suitable scale. The lengths of the ripples can thus be obtained by micrometric measurements of

the negative. The results obtained for mercury were very concordant and agreed with the mean value obtained by Quincke. Strong electrification of the surface reduced the value of the surface tension by more than 20 per cent.—*Nature*, April 17, 1890. J. T.

7. *Suppression of Photographic Halos.*—MM. PAUL HENRY and PROSPER HENRY state that these halos can be obviated by covering the back of the negative with a film of collodion which contains in solution a small quantity of *chrysoïdine*. This varnish has an index of refraction which differs slightly from that of glass. The halos from even the most brilliant stars are suppressed completely by it. The varnish dries rapidly and is perfectly transparent.—*Comptes Rendus*, April 8, 1890, p. 751.

J. T.

II. GEOLOGY AND MINERALOGY.

1. *The Potomac or Younger Mesozoic Flora;* by WM. M. FONTAINE. Monographs of the U. S. Geological Survey, vol. xv, Washington, 1880. Text 377 pp. 4°. Atlas 180 plates, bound separately.—This highly important and long looked-for work, though bearing date 1889, did not appear until late in the spring of the present year. Ever since the announcement of its general nature and contents in the number of this Journal for August 1888 (vol. xxxvi, p. 119), anxious inquiries have been coming in as to when it would be in the hands of scientific men. It is now before the world and is all that its title indicates. As a revelation of the hidden treasures of a little known deposit, placing the appearance of the most prominent type of vegetation a long way farther back in time than it had hitherto been recorded, it cannot fail to awaken a lively interest among geologists and paleontologists, while as a monument of prolonged and patient labor in a most difficult field of research, it reflects the highest credit upon its author. It would be impossible to do justice in a brief notice to a work of this nature. Suffice it to say that it is chiefly a record of the facts, the important deductions that flow from these being modestly left to the reader. Three hundred and sixty-five species of fossil plants are described in the text and profusely illustrated. The drawings, all by the author's own hand, were a little too realistic for the process employed in their reproduction, by which the perfection of the work suffers somewhat through no fault of his. Professor Fontaine may almost be said to have discovered this flora, and nearly every specimen was collected by himself in the soft clays and preserved with the utmost difficulty. Whatever may be the true age of this formation the fossil plants must constitute the chief factor in determining it. L. F. W.

2. *Geological Survey of Missouri, Bulletin No.* 1.—This first Bulletin of the Survey contains after the Administrative Report of the State Geologist, Arthur Winslow, an account of the Coal beds of Lafayette Co., by Mr. Winslow; of the Building Stones and Clays, and Iron sands of St. François and Madison Cos., by G. E. Ladd; the Mineral waters of Saline Co., by A. E. Wood-

ward; and a preliminary account of the fossils occurring in Missouri, with a table giving their localities and geological periods, by G. Hambach.—Mr. Winslow states that the investigation of the Zinc and Lead Regions is under the charge of Mr. Walter P. Jenney, of the U. S. Geological Survey. Missouri is a rich State in economical mineral materials and in the scientific interest of its geology, and much is to be expected from this new survey.

3. *A preliminary Check list of the Cretaceous Invertebrate fossils of Texas*, accompanied by a short description of the lithology and stratigraphy of the system, by R. T. Hill. Bulletin No. 4 of the Geological Survey of Texas, E. T. Dumble, State Geologist.—A valuable Catalogue of Texas Cretaceous fossils, in which the species of the Lower Cretaceous thus far described are referred to their right places in the series. It was prepared for the use of the Survey and not as the final result of its work.

4. *Geological Map of Scandinavia.* — A small geological map, handsomely colored, prepared by the excellent geologist of Christiania, Dr. Hans Reusch, has recently been published by H. Aschehoug & Co. of Christiania. Upon it are geological maps also of Iceland, Spitzbergen, and the Færö Islands. It is accompanied by an explanatory pamphlet of 32 pages.

5. *Gems and Precious Stones of North America.*—A popular description of their occurrence, value, history, archæology, and of the collections in which they exist; also a chapter on pearls and on remarkable foreign gems in the United States. 336 pp. large 8vo, with 8 colored plates; by George Frederick Kunz. New York, 1890 (The Scientific Publishing Company). —The American reader, who is attracted to the subject of gems, will find much to interest and instruct him in the handsome volume by Mr. Kunz. Starting off in each chapter with a brief mineralogical description of the species under discussion, the author goes on to give a detailed account of its occurrence in this country, the value of the stones found, the present owners of the finest ones and other allied points, embracing much information which has not been brought together before, and which the author's position has given him peculiar facilities for collecting. The fact that the book has been written in popular form for the general public should give it a wide range of readers. At the same time this removes it from the kind of criticism to which a work striving for minute scientific accuracy would be liable. The publishers have shown much enterprise in the handsome form in which the book has been put as regards paper and press work, and the numerous colored plates which ornament it are of very unusual excellence; it is rare indeed that the delicate coloring of the various gem stones, and of the natural mineral specimens, has been reproduced so faithfully.

III. Miscellaneous Scientific Intelligence.

1. *Fall of Meteorites in Iowa*; by Joseph Torrey, Jr., and Erwin H. Barbour. (Communicated.)—The large and brilliant meteor which fell in northern Iowa on the afternoon of May 2d,

at 5.30 was widely observed throughout the adjoining country. It appears that the phenomenon was rather in the nature of a meteoric shower, judging by appearances and the fact that several complete meteorites of considerable size—10, 70, 100 pounds—have been found, at long distances from each other, with a large number of smaller ones. The splendor of this great luminous ball—bright even in full sunlight—its fiery comet-like tail, three to four degrees in length, and the long train of smoke lingering behind it fully ten minutes plainly marking its course in the sky, inspired all who saw it with awe. It is described as sputtering throughout its course like fireworks. To the students who saw it enter the atmosphere, it appeared to start a few degrees below the zenith, and to pass below the horizon to the N.N.W. of this place, descending at an angle of fifty degrees. The meteoric shower covered an area, some two to three miles wide, near Forest City, Winnebago Co., Iowa, while one meteorite, weighing one hundred pounds, passed into Kossuth Co. We were so fortunate as to secure several fragments broken from the seventy pound mass, together with a rather small, but complete and characteristic meteorite, weighing one fifth of a pound. These meteorites belong to the "Stone" class. Their most noticeable feature is the large amount of metal contained in the fragments examined, it amounting to 45 per cent by weight. The metal is in exceedingly small globules and thin flakes, making its separation from the matrix a matter of considerable difficulty. The matrix has been analyzed by us with the following results:

SiO_2 47·03, Fe_2O_3 29·43, Al_2O_3 2·94, CaO 17·58, MgO 2·96=99·94.

Specific gravity of matrix 2·63, of the metal freed from matrix as well as possible at present 5·75. As early as is consistent with accuracy, these preliminary notes will be followed with a full report on this important meteor.

Iowa College, Grinnell, Iowa, May 9, 1890.

2. *Orbit of the Meteor of May 2d.*—The newspaper accounts of the path of the Iowa meteorite of May 2d are definite enough to give a fair idea of its orbit about the sun before entering the atmosphere. The path that satisfies best the accounts that appear to be reliable was directed from a point a little north of west and somewhat higher than the sun,—the sun being then about 20° high and due west. The velocity of the meteorite may be safely assumed to have been greater than that of Encke's comet at distance unity, and less than that belonging to a parabolic orbit. With this assumption the orbit would be inclined to the ecliptic between 10 and 20 degrees with direct motion. The ascending node is in longitude 42°·5. The body had passed perihelion several weeks, how long depends mainly upon the inclination to the horizon of the path through the air. The perihelion distance was probably between ·50 and ·70, this element also being largely dependent upon the same inclination. Better observations of this inclination than are now in hand are hoped for.

H. A. N.

APPENDIX.

ART. LIX.—*Notice of New Tertiary Mammals;* by O. C. MARSH.

RECENT researches in the Tertiary deposits of the West have made known several new forms of large mammals, some of which are here briefly described. All the latter are from the Brontotherium beds of Dakota, and show a closer connection of the fauna of these deposits with that below than has hitherto been suspected. They will all be described more fully by the writer in a later communication.

Diploclonus amplus, gen. et sp. nov.

The type-specimen of this genus is a nearly complete skull, in good preservation, but without the lower jaws. One of the most marked features is seen in the horn-cores, which are high, compressed transversely, and have a prominent knob on the inner superior margin, about one-third of the distance to the summit. Seen from the front, the horn-cores thus appear to be branched. It is probable that in life this feature was still more evident, and the covering of the horn-core may have shown an actual division, but this cannot be determined from the present specimen. There is a sharp ridge at the base of the horn-cores on the outside.

The nasals project but very little in front of the horn-cores. The zygomatic arches are especially strong, and widely expanded. The posterior nares have their front margin opposite the back of the last upper molars.

There were apparently but two upper incisors, and no diastema exists behind the canines. The premolars have a strong inner basal ridge, and the last upper molar has two inner cones.

This genus appears to be most nearly related to *Titanops*, but the horn-cores will distinguish it readily from all known forms of the *Brontotheridæ*.

The skull measures twenty-eight inches from the front of the nasals to the back of the occipital condyles, and twenty-four inches in greatest width across the zygomatic arches. The space occupied by the upper dental series is thirteen and one-half inches, and by the true molars, eight inches.

Teleodus avus, gen. et sp. nov.

The present genus is allied to *Brontotherium*, but differs from it in having six lower incisors instead of four. It has the same number of inferior premolars and molars, and these teeth are similar in the two genera. From *Diplacodon* of the Upper Eocene, the present genus may be distinguished by having only three lower premolars on a side instead of four. The type-specimen indicates an old animal, somewhat smaller than *Brontotherium gigas*.

Of the three lower incisors in place on each side, the middle one is the largest. There is a short diastema behind the lower canine, but no first premolar. The dental formula of the lower jaws is as follows:

Incisors, 3; canine, 1; premolars, 3; molars, 3.

The space occupied by the lower dental series is fourteen and one-half inches, and by the last three molars, eight and one-half inches.

Colodon luxatus, gen. et sp. nov.

The present genus appears to be nearly allied to *Lophiodon*, but may be distinguished from it by the upper premolars having two inner cones, and by the absence of canines in the lower jaws. The upper and lower true molars are of the same general structure as those of *Lophiodon*. From *Hyrachyus*, of the Eocene, the upper premolars, the absence of canines below, and the last lower molar with a posterior lobe, will separate it. The present genus is probably a lineal descendant of the Eocene *Helatetes*, and an intermediate form between that genus and *Tapiravus* of the Pliocene. The lower dental series has the following formula:

Incisors, 3; canine, 0; premolars, 3; molars, 3.

This series occupies in the type-specimen a space of five and one-half inches, and the last three lower molars, two inches.

Hyopotamus deflectus, sp. nov.

A second American species of the genus *Hyopotamus* is indicated by the greater portion of a skull with lower jaws, recently found in the Miocene of Dakota. These belonged to an animal about the size of *Hyopotamus Americanus*, Leidy, of which teeth only are known.

The two forms may readily be distinguished by the last upper molar, which, in the latter species, has the middle anterior cusp situated almost directly between the outer and the inner cones. In the present specimen, this cusp is placed in front of the other two, the posterior margin of its base reaching only to the middle of the main cones.

The postorbital processes are long, and more nearly close the orbit behind, than in the other known species of this genus.

The space occupied by the last six teeth of the upper premolar and molar series is four and three-fourth inches, and by the corresponding lower series, five inches. The distance from the last upper molar to the back of the occipital condyles is four and one-half inches.

Limnohyops laticeps, gen. nov.

In 1872, the writer described a large mammal from the Eocene of Wyoming under the name *Palæosyops laticeps*.* As the name *Palæosyops* has since been restricted, this species must be regarded as representing a distinct genus, which may be called *Limnohyops*. In this form, the last upper molar has two inner cones, and in *Palæosyops*, as now defined, there is only one.

New Haven, Conn., May 21, 1890.

* This Journal, vol. iv, p. 122, August, 1872.

PUBLICATIONS OF ELIAS LOOMIS.

1. On shooting stars. *Am. Jour.* (1), vol. 28, pp. 95–104. April, 1835.

2. Halley's comet (Olmsted and Loomis). *New Haven Daily Herald*, September 1, September 4, September 28, and December 31, 1835.

3. Halley's comet (Olmsted and Loomis). *Am. Jour.* (1), vol. 29, pp. 155–156. October, 1835.

4. Observations on the comet of Halley, made at Yale College. *Am. Jour.* (1), vol. 30, pp. 209–221. July, 1836.

5. Observations on the variation of the magnetic needle, made at Yale College in 1834 and 1835. *Am. Jour.* (1), vol. 30, pp. 221–233. July, 1836. (*Sturgeon's Ann. Electr.*, vol. 2, pp. 270–282.)

6. Letters from Europe. (Thirty-six letters.) *Ohio Observer* (1837).

7. Meteoric shower of November 13. *Cleveland Observer*, November, 1837.

8. Hourly meteorological observations for the December solstice of 1837, made at Western Reserve College. *Cleveland Observer*, December 23, 1837.

9. Hourly meteorological observations for the vernal equinox of 1838, made at Western Reserve College. *Cleveland Observer*, March, 1838.

10. Observations on a hurricane which passed over Stow, in Ohio, October 20, 1837. *Am. Jour.* (1), vol. 33, pp. 368–376. January, 1838.

11. Splendid meteor (May 18, 1838). *Cleveland Observer*, May 22, 1838.

12. Hourly meteorological observations for the summer solstice of 1838, made at Western Reserve College. *Cleveland Observer*, June, 1838.

13. On the variation and dip of the magnetic needle in different parts of the United States. *Am. Jour.* (1), vol. 34, pp. 290–309. (With a map.) July, 1838.

14. On the latitude and longitude of Yale College Observatory. *Am. Jour.* (1), vol. 34, pp. 309–313. July, 1838.

15. Meteors of August 9. *Cleveland Observer*, August 11, 1838.

16. An inaugural address, delivered August 21, 1838. 8vo, pp. 38. New York, 1838.

17. Hourly meteorological observations for the autumnal equinox of 1838, made at Western Reserve College. *Cleveland Observer*, September, 1838. (Professor Loomis also observed on the term days in December, 1838, and in March and June, 1839.)

18. On the meteor of May 18, 1838, and on shooting stars in general. *Am. Jour.* (1), vol. 3, pp. 223–232. January, 1839.

19. Meteorological table and register. *Am. Jour.* (1), vol. 36, pp. 165–173. April, 1839.

20. Observations to determine the magnetic dip at various places in Ohio and Michigan. In a letter to Sears C. Walker, Esq. Read June, 1839. *Am. Phil. Soc. Trans.*, vol. 7, pp. 1–6. (*Am. Phil. Soc. Proc.*, vol. 1, p. 116; *Am. Jour.* (1), vol. 38, p. 397.)

21. Astronomical observations made at Hudson Observatory, latitude 41° 14′ 37″ north and longitude 5^h 25^m 42^s west, with some account of the building and instruments. (Latitude of observatory; moon culminations; occultations.) *Am. Phil. Soc. Trans.*, vol. 7, pp. 43–51. Read October, 1839. (*Am. Phil. Soc. Proc.*, vol. 1, pp. 129–130.)

22. Additional observations of the magnetic dip in the United States. *Am. Phil. Soc. Trans.*, vol. 7, pp. 101–111. Read October, 1839. (*Am. Phil. Soc. Proc.*, vol. 1, pp. 144–145.)

23. On the storm which was experienced throughout the United States about the 20th of December, 1836. *Am. Phil. Soc. Trans.*, vol. 7, pp. 125–163. (With three plates.) Read March, 1840. (*Am. Phil. Soc. Proc.*, vol. 1, pp. 195–198; *Am. Jour.* (1), vol. 40, pp. 34–37.)

24. Meteorological sketches. (Eight papers.) *Ohio Observer*, 1840.

25. On the variation and dip of the magnetic needle in the United States *Am. Jour.* (1), vol. 39, pp. 41–50. (With a map.) July, 1840.

26. Observations to determine the magnetic intensity at various places in the United States, with some additional observations of the magnetic dip. *Am. Phil. Soc. Trans.*, vol. 8, pp. 61–72. Read November, 1840. (*Am. Phil. Soc. Proc.*, vol. 2, pp. 308–310.)

27. On the magnetic dip in the United States. *Am. Jour.* (1), vol. 40, pp. 85–92. (*Sturgeon's Ann. Electr.*, vol. 7, pp. 156–162.) January, 1841.

28. Meteorological observations made at Hudson, Ohio, latitude 41° 14′ 40″ north, longitude 5^h 25^m 47.5^s west, during the years 1838, 1839, and 1840. (Barometer; thermometer and hygrometer; winds; rain.) *Am. Jour.* (1), vol. 41, pp. 310–330. October, 1841.

29. Astronomical observations made at Hudson Observatory, latitude 41° 14′ 40″ north and longitude 5^h 25^m 45^s west. (Latitude of observatory; moon culminations; occultations; comet 1840, II; orbit of comet.) *Am. Phil. Soc. Trans.*, vol. 8, pp. 141–154. Read April, 1841.

30. On the dip and variation of the magnetic needle in the United States. *Am. Jour.* (1), vol. 43, pp. 93–116. April, 1842.

31. Encke's comet. *Ohio Observer*, April, 1842.

32. On a tornado which passed over Mayfield, Ohio, February 4, 1842, with some notices of other tornadoes. *Am. Jour.* (1), vol. 43, pp. 278–300. (With a map.) April, 1842.

33. Supplementary observations on the storm which was experienced throughout the United States about the 20th of December, 1836. *Am. Phil. Soc. Trans.*, vol. 8, pp. 305–306. Read May, 1842.

34. Observations on the magnetic dip in the United States. *Am. Phil. Soc. Trans.*, vol. 8, pp. 285–304. Read May, 1842. (*Am. Phil. Soc. Proc.*, vol. 2, pp. 176–178.)

35. Icebergs in the Atlantic. *Ohio Observer*, July, 1842.

36. The comet. (Five papers, with orbit.) *Ohio Observer*, March, 1843.

37. On two storms which were experienced throughout the United States in the month of February, 1842. *Am. Phil. Soc. Trans.*, vol. 9, pp. 161–184. (With 13 maps.) Read May, 1843. (*Am. Phil. Soc. Proc.*, vol. 3, pp. 50–56.)

38. On vibrating dams. *Am. Jour.* (1), vol. 45, pp. 363–377. (Cuyahoga Falls; East Windsor; Springfield; Northampton; Gardiner; Hartford.) October, 1843.

39. Meteorological journal kept at Western Reserve College. (Forty-seven papers.) March, 1840, to January, 1844. *Ohio Observer.*

40. Modern astronomy. *New Englander*, vol. 2, pp. 3–18. January, 1844.

41. Comparison of Gauss's theory of terrestrial magnetism with observation. *Am. Jour.* (1), vol. 47, pp. 278–281. October, 1844.

42. Astronomical observations made at Hudson Observatory, latitude 41° 14′ 42.6″ north and longitude 5^h 25^m 39.5^s west. Third series. *Am. Phil. Soc. Trans.*, vol. 10, pp. 1–15. Read November, 1844. (*Astron. Nachr.*, vol. 22, pp. 203–210, No. 517, October, 1844. *Roy. Astr. Soc., Month Notices*, December, 1844.) (Latitude of observatory; moon culminations; occultations; longitude of observatory; Encke's comet; comet of 1843; Mauvais's comet; Faye's comet.)

43. Meteorological observations made at Hudson, Ohio, latitude 41° 14′ 42″ north, longitude 5^h 25^m 40^s west, during the years 1841, 1842, 1843, and 1844, with a summary for seven years. (Barometer; thermometer and hygrometer; winds; clouds; rain.) *Am. Jour.* (1), vol. 49, pp. 266–283. October, 1845. (*Astr. Nachr.*, vol. 22, pp. 203–210.)

44. Physical constitution of the moon. *Sidereal Messenger*, vol. 1, pp. 20–22. September, 1846. (*Am. Jour.* (2), vol. 2, pp. 432–433.)

45. A treatise on algebra. 12mo, pp. 346. New York, 1846.

46. On Biela's comet. *Am. Jour.* (2), vol. 2, pp. 435–438. November, 1846.

47. The planet Neptune. *Am. Review*, vol. 6, pp. 145–155. August, 1847.

48. On the determination of differences of longitude made in the United States by means of the electric telegraph, and on projected observations for investigating the laws of the great North American storms. (Letter to Lieutenant Colonel Sabine.) *Phil. Mag.*, 3d series, vol. 31, pp. 338–340. August, 1847.

49. Notice of some recent additions to our knowledge of the magnetism of the United States and its vicinity. *Am. Jour.* (2), vol. 4, pp. 192–198. September, 1847.

50. Elements of geometry and conic sections. 8vo, pp. 222. New York, 1847.

51. Notice of a water-spout. *Am. Jour.* (2), vol. 4, pp. 362–364. November, 1847.

52. Report on the meteorology of the United States, submitted to the Secretary of the Smithsonian Institution. *Sen. Doc.* No. 23, 30th Congress, first session, pp. 193–207. Ordered printed January, 1848.

53. Historical notice of the discovery of the planet Neptune. *Am. Jour.* (2), vol. 5, pp. 187–205. March, 1848.

54. Note respecting Halley's comet. *Am. Jour.* (2), vol. 5, pp. 370–372. May, 1848.

55. The relations of Neptune to Uranus. *Am. Jour.* (2), vol. 5, pp. 435–437. May, 1848.

56. Elements of plane and spherical trigonometry, with their applications to mensuration, surveying, and navigation. 8vo, pp. vi, 148. New York, 1848.

57. Tables of logarithms of numbers and of lines and tangents for every ten seconds of the quadrant, with other useful tables. 8vo, pp. xvi, 150. New York, 1848.

58. On the determination of the difference of longitude by means of the magnetic telegraph. *Roy. Soc. Proc.*, vol. 5, pp. 787–789. 1849.

59. Experiments on the electricity of a plate of zinc buried in the earth. *Am. Jour.* (2), vol. 9, pp. 1–11. January, 1850. (*Am. Assoc. Proc.*, pp. 196–200, 1849. *Bibl. Univ., Archives*, vol. 13, pp. 265–281.)

60. On the longitude of Hudson (Ohio) Observatory. *Astron. Jour.*, Nos. 8 and 9. May, 1850.

61. On the proper height of lightning rods. *Am. Jour.* (2), vol. 10, pp. 320–321. (Read August, 1850.) (*Am. Assoc. Proc.*, pp. 38–43. 1850.)

62. On the electrical phenomena of certain houses. *Am. Jour.* (2), vol. 10, pp. 321–323. (Read August, 1850.) (*Am. Assoc. Proc.*, pp. 12–15, 1850. *Edin. New Phil. Jour.*, vol. 50, pp. 225–227.)

63. On optical moving figures. *Am. Assoc. Proc.*, pp. 293–295. 1850.

64. The recent progress of astronomy, especially in the United States. 8vo, pp. 257. New York, 1850.

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